ICES WGMASC REPORT 2008
ICES MARICULTURE COMMITTEE

ICES CM 2008/MCC:02

Ref. ACOM

Report of the Working Group on Marine Shellfish Culture (WGMASC)

1–3 April 2008

Aberdeen, UK

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

H. C. Andersens Boulevard 44–46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

Recommended format for purposes of citation:

ICES. 2008. Report of the Working Group on Marine Shellfish Culture (WGMASC), 1–3 April 2008, Aberdeen, UK. ICES CM 2008/MCC:02. 71 pp.

Contents

Executive summary

The sixth meeting of the Working Group on Marine Shellfish Culture [WGMASC] (Chair: Peter Cranford, Canada) was held in Aberdeen (Scotland) and attended by 11 participants.

ToR a) The following priority emerging shellfish aquaculture issues were identified: (1) driving factors, advantages, optimization and effects of new technologies used to culture shellfish both offshore and on land; (2) alternative and value-added uses of cultured shellfish; and (3) ecological carrying capacity for shellfish aquaculture (Section 3; linkages to WGEIM, MCC, ACME).

ToR b) A variety of approaches and tools are being evaluated and integrated into a recommended ecosystem-based management framework for shellfish aquaculture. General management approaches were identified that consider all anthropogenic activities (ICZM) and indicator-based management frameworks that deal with the concept of driving forces, impacts and responses, and impact assessment approaches and tools are reviewed. Specific shellfish aquaculture management issues are addressed including identification of effective environmental indicators, the management applications of modelling, and thresholds of ecological and potential public concern. Highlights include recommendations on: (1) the use of shellfish-ecosystem models in the development of ecological indicators and thresholds of potential concern; (2) bridging science and policy through the identification of indicators and associated management thresholds; and (3) linking socio-economical sciences with ecological sciences to (a) define “acceptable” levels of impact by clarifying the values and expectations of different groups, (b) contribute to economic evaluation of environmental services, and (c) to help understand the interaction of processes, objectives and institutional arrangements across multiple temporal and geographical scales (Section 4; linkages to MCC, ACME, WGEIM, WGICZM).

ToR c) The movement and translocation of live shellfish and shells from hatcheries and field sites around the world has a long history with the development of resources, driven by an economic objective. Such movements can involve the introduction non-indigenous species, diseases, parasites and harmful algae. Potential implications to wild and cultured stocks include impacts on recruitment, loss of cultivated organisms, sterilization, reduced fitness, fecundity and meat content, increased competition and predation, and change in genetic composition, diversity and polymorphism, and physiological and morphological traits. To prevent overlap with activities of other ICES expert groups, the WGMASC focuses on the significance of bivalve aquaculture transfers to resident wild and cultured bivalve stocks. Information is being gathered on guidelines for the transfer of cultured shellfish in ICES countries and what records are kept. Effects of shellfish relocations and available decision support tools are being reviewed and recommendations to farmers and policy makers are in development to support policy decisions on cultured shellfish transfers (Section 5; linkages to MCC, ACME, SGBOSV, WGITMO, and WGEIM).

ToR d) Preliminary work has been undertaken to review the state of knowledge on the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries world wide. Climate changes will ultimately have a direct impact on world ecosystems, determining which shellfish species are suitable for farming in a given region and will indirectly influence other factors that influence aquaculture (primary production, microalgal biodiversity, the presence of nuisance

species, oxygen levels, the incidence of harmful algal blooms, sea level rise, salinity, ocean pH, weather extremes, storm surges, tidal regimes, waves, coastal erosion, etc.). As a first step to addressing the potential implications of climate change to aquaculture, a work plan has been established, observations and model scenarios of coastal and ocean climate change are being compiled and a preliminary literature conducted (Section 6; linkages to MCC, ACME, WGEIM).

1 Opening of the meeting

The ICES Working Group on Marine Shellfish Culture [WGMASC], chaired by Peter Cranford (Canada), held its sixth meeting in Aberdeen (Scotland) on 1–3 April 2008 at the Fisheries Research Services, Marine Laboratory.

The meeting was opened at 9:30 on Tuesday 1 April, with David Fraser and Rob Raynard welcoming the group to The Marine Laboratory. The Chair welcomed the members to the meeting, including three new common members (Gesche Krause, Germany, Adoracion Sanchez Mata, Spain and Michael Gubbins, UK) and a chair appointed member (Kris Van Nieuwenhove, Belgium), who is awaiting appointment as a common member. The Chair presented an overview of proposed ICES Science Structure organization plans, the 2007 recommendations from the MMC, and the joint WGEIM and WGMASC theme session on "Ecological Carrying Capacity in Shellfish Culture" to be held at the ICES ASC 2008 in Halifax.

The WGMASC Terms of Reference (Annex 1) were reviewed. Two of four ToR's are ongoing, with two new ToRs (c and d) added for 2008 based on 2007 recommendations from the WGMASC. The opening plenary session included a general discussion of plans for addressing each ToR. ToR a) is expected to remain ongoing for brief discussion at each annual meeting. ToR b) will remain ongoing for approximately two more years (final report in 2010) to address the many linked activities that make up a framework for the integrated evaluation and management of the impacts of shellfish aquaculture in the coastal zone. ToRs c) and d) are new, and the time span to a final report is not yet resolved.

2 Adoption of the agenda

A general discussion was held on how the WGMASC should organize the work under each of the four Terms of Reference. The WGMASC decided to continue the past practice of addressing most ToRs separately within subgroups, followed by plenary sessions where subgroup activities are discussed by the full WGMASC and the draft report is formally accepted. ToRs b), c), and d) were decided to be addressed concurrently by subgroups, while ToR a) is addressed in plenary sessions. The agenda (Annex 2) was formally accepted during the opening plenary.

Subgroup leaders appointed by the WGMASC Chair were Peter Cranford (ToR b), Pauline Kamermans (ToR c), and Øivind Strand (ToR d). Each subgroup leader acted as rapporteur for preparing draft reports from the work of subgroups and reported on their group's activities during plenary sessions.

3 Identify emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. (ToR a)

The task was to briefly highlight new and/or important issues that may require immediate additional attention by the WGMASC and/or other Expert Groups as opposed to providing a comprehensive analysis. Two high priority issues identified in the 2007 WGMASC report have been approved as new ToRs to be addressed in this report Tors c) and d). The following issues were identified by the working group for future attention and communication.

Relatively high priority:

1) New technologies used to culture shellfish both offshore and on land.

- What factors drive such technologies?
    - Is there pressure in some regions to reduce shellfish production in coastal areas or move aquaculture offshore and on-land?
    - Are there possibilities to combine existing offshore structures to minimize a negative impact on the ecosystem, to minimize costs and to guarantee co-management for saving labour?
    - Are shellfish hatcheries an efficient solution to wild population recruitment problems? What are the advantages and disadvantages of wild vs. hatchery recruitment (partially addressed in ToR c) of 2007 WGMASC report), such as the potential impacts associated with transfers?
- What are their benefits and disadvantages of relocating aquaculture and using new technologies?
- What is the shellfish production potential compared to traditional cultures?
- What species are most suited to such technologies and what are limiting factors for their production?
- What are the environmental implications of utilizing new technologies for culturing shellfish in alternative areas including exposed, high energy, oceanic environments and practicalities such as servicing and harvesting from sites in remote locations?

2) What are the alternative and value-added uses of cultured shellfish? How can alternative uses result in increased production levels, value and benefits in distribution?

3) Ecological carrying capacity models are at an early stage of development, but have the potential to feed into ecosystem-based management systems for marine areas. In addition, they support the goals of the ecosystem approach and aid in the identification of effects indicators and thresholds of potential concern. Further development and application of such models is an important sustainability issue.

Other emerging issues:

4) How do social values and administrative organizations in different countries/regions impact trends in the intensity, methodology, structure and type of aquaculture?

4.1) Is industrialization an advantage or should culture be kept at a smaller farmer scale?

4.2) What are the current trends in shellfish consumption by region? Are they changing? What social factors drive aquaculture trends and what are the sources (emerging or traditional)? Can these trends be used to identify new culture species and to determine the potential for expansion? Do changing trends suggest a need for additional research into impacts?

5) What foreign sources (past or emerging) fulfil the European and North American deficit of mollusc products?

6) Investigate issues raised by some farmers regarding test results used to regulate classification of waters and the impact of algal toxins on shellfish production. Are more sensitive and efficient (fast) tests and monitoring protocols needed? Should viral contamination and alternative indicators also be used? Should standardization, accreditation and routine auditing be required across different jurisdictions?

7) Investigate global sustainability issues related to consumption of wild and cultured shellfish. Can the ecological footprint at the local scale be significantly reduced by consuming local shellfish production? Is the productive capacity of shellfish significantly greater compared with harvesting at higher trophic levels? Can shellfish productive capacity be significantly increased through engineering (e.g. artificial upwelling, multi-trophic aquaculture)? Balance the health risks and benefits (e.g. nutritional, medicinal) of consuming shellfish. Utilize the results to promote more favourable policies for expansion of aquaculture.

The following sections briefly provide background on the higher priority issues identified above and identify some related advisory and research needs.

3.1 Driving factors and resulting new technologies for culturing shellfish both offshore and on land?

Competition for aquaculture space in coastal areas, the need for suitable water quality and technological advances in shellfish culture structures has increased interest in the use of some non-traditional culture sites, including the offshore and land-based culture. New production methods (technology and system design, planning) (Buck 2007; Buck and Buchholz 2004) and management strategies (Buck *et al.* 2004) need to be identified to minimize the potential for negative impacts in coastal zone. As expected for any new operation, the question of environmental and socio-economic impacts at offshore sites has received relatively little attention. There is a need to assess potential environmental interactions of these operations, to analyse scientific evidence for impacts documented in environmental impact assessments, and to set environmental standards. The scientific evidence regarding advantages associated with offshore culture also needs to be analysed. Directed research is required to predict and detect potential interactions in alternative culture areas, and to develop best management approaches for this expanding industry. Both offshore and land-based shellfish culture are still in an experimental stage and up-to-date information is needed on production potential and costs to improve comparison with traditional methods in coastal areas. Consideration should also be given as to which species are most suited to these novel technologies, what limiting factors affect their production and practicalities such as servicing, feeding, transporting and harvesting from sites in remote locations.

3.2 Identify alternative and value added uses of cultured shellfish

Opportunities are available to the shellfish aquaculture industry to expand beyond the traditional role as food suppliers and to produce value added niche products, whether in the presentation of existing products or for new and novel uses. Shellfish are excellent nutritional sources and shellfish extracts have potential pharmaceutical functions (e.g. extraction of Omega-3 polyunsaturated fatty acids; and therapeutic potential for the treatment of inflammation and inflammatory conditions such as rheumatoid arthritis (McPhee *et al.*, 2007)). Utilization of all parts of the animals is also encouraged to reduce wastes and to increase profitability. The culture of Japanese scallop is a good example of waste reduction through the marketing/utilization of the whole animal. Another example is the utilization of the bivalve shell. Shells are used as insulation for housing and as material in road construction. A recent example of a non-traditional use of shellfish culture results from suggestions that bivalve aquaculture may help ameliorate the impacts of nitrogen enrichment in eutrophic coastal waters by removing excess nitrogen in the shellfish harvest (e.g. Rice 2000; 2001). This has led to the proposition that shellfish aquaculture be incorporated in a nutrient trading system as an alternative to nitrogen reduction for improving coastal water quality (Lindahl *et al.*, 2005). However, such a scheme may, under some conditions, may lead to unexpected deleterious results (Cranford *et al.*, 2007). The diversified production, including shellfish, associated with integrated multi-trophic aquaculture (IMTA) is an effective means of recycling aquaculture wastes and provides a more beneficial use/conversion of introduced food and energy.

Research priorities related to these alternative uses of shellfish culture include;

- potential additional pharmaceutical uses of cultured shellfish,
- quantitative assessments of the value of shellfish culture in nutrient trading ventures (e.g. Cranford *et al.* 2007),
- identification of environmental aspects of IMTA, including carrying capacity, diseases, predator-prey interactions and environmental impacts, and
- impacts of regulations related to utilization of shell (e.g. shell introductions for marine uses).
- Investigations on how can value added product result in increased production levels, value and benefits in distribution.

3.3 Ecological Carrying Capacity and Shellfish Culture

The ability to predict carrying capacity is crucial to expanding large-scale bivalve aquaculture operations. To date, the development of models has focused on identifying production carrying capacity, which is the theoretical maximum bivalve culture that could be supported in an embayment. With the development of the ecosystem approach to providing advice for the management of marine ecosystems, there has been a change in focus from the maximum sustainable yield of the culture (i.e. an economic and farm management perspective) to consideration of significant changes in ecological energy flow, material fluxes, and the structure of the food web (ecosystem perspective). The development of ecological carrying capacity models is still in its infancy but has the potential to feed into ecosystem-based management systems for marine areas. In addition, they reflect the ideals and goals of the ecosystem approach. Continuing work on the following topics is needed;

- definition of ecological carrying capacity including discussion of theoretical and socio-economic considerations towards defining an "unacceptable" ecological impact (i.e. identification of the critical limits and thresholds at which the levels of shellfish aquaculture stress lead to the disruption of the system),
- time-series observations of ecological responses to shellfish aquaculture development,
- research on the development, value and application of predictive ecological models in shellfish aquaculture systems,
- site-specific factors affecting ecological carrying capacity,
- direction for scientists from stakeholders (e.g. habitat and farm managers and non-governmental organizations) on potential components of interest that need to be evaluated in unbiased ecological carrying capacity assessments, and
- discussion on how models of aquaculture systems complement the ecosystem approach to marine management.

Towards addressing this issue, the 2008 ICES ASC has included a theme on this topic (Theme H) that stems from joint recommendations by the WGEIM and the WGMASC.

3.4 Recommendation

The WGMASC recommends to continue to identify and report on emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. This continued discussion is important to identifying future ToRs for the WGMASC and perhaps for other expert groups.

3.5 References

Buck, B. H., Buchholz, C. M. 2004. The Offshore-Ring: A new system design for the open ocean aquaculture of macroalgae, Journal of Applied Phycology, 16(5), 355–368, doi:10.1023/B:JAPH.0000047947.96231.ea .

Buck, B. H. 2007. Experimental trials on the feasibility of offshore seed production of the mussel Mytilus edulis in the German Bight: Installation, technical requirements and environmental conditions, Helgoland Marine Research, 61, 87–101, doi:10.1007/s10152–006–0056–1

Buck, B. H., Krause, G., Rosenthal, H. 2004. Extensive open ocean aquaculture development within wind farms in Germany: the prospect of offshore co-management and legal constraints, Ocean & Coastal Management, 47(3–4), 95–122, doi:10.1016/j.oecoaman.2004.04.002

Cranford, P.J., Strain, P.M., Dowd, M., Hargrave, B.T., Grant, J., and Archambault, M.-C. 2007. Influence of Mussel Aquaculture on Nitrogen Dynamics in a Nutrient Enriched Coastal Embayment. Mar. Ecol. Prog. Ser., 347: 61–78.

Lindahl, O., Hart, R., Hernroth, B., Kollberg, S., Loo, L.-O., Olrog, L., Rehnstam-Holm, A.-S., Svensson, J., Svensson, S., Syversen, U. 2005. Improving marine water quality by mussel farming: a profitable solution for Swedish society. Ambio, 34: 131–8.

McPhee, S., Hodges, L. D., Wright, P.F.A., Wynne, P.M., Kalafatis, N., Harney, D.W., Macrides, T.A. 2007. Anti-cyclooxygenase effects of lipid extracts from the New Zealand greenlipped mussel, *Perna canaliculus* Comparative Biochemistry and Physiology, Part B 146: 346–356.

Rice, M.A. 2000. Filter Feeding to Control Eutrophication, Environment Cape Cod, 3: 1–8.

Rice, M.A. 2001. Environmental impacts of shellfish aquaculture: filter feeding to control eutrophication. *In*: Tlusty M.F., Bengston D.A., Halvorson H.O., Oktay S.D., Pearce J.B., Rheault R.B.Jr. (eds) Marine aquaculture and the marine environment: A meeting of stakeholders in the northeast. Cape Cod Press, Falmouth, p 76–86.

4 Complete the development of a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone (ToR b)

4.1 Background

There are many components and tools that need to be developed and integrated into an ecosystem management framework for the evaluation of shellfish aquaculture impacts on the coastal zone. Components include: hazard identification; environmental exposure and risk assessments (including predictive modelling); risk management; cost-benefit analysis; environmental indicator monitoring; effects management based on indicator threshold values; implementation of mitigation measures; utilization of decision support tools for responsive ecosystem management; and communication. Addressing this ToR therefore required the development of a multi-year work plan and the progressive annual reporting on components of the recommended ecosystem management framework for shellfish aquaculture. The following sections continue the work plan initially reported by the WGMASC in 2006. Progress in 2008 included overall editing and updating of this draft ToR b) report with a focus on including (1) new developments in Integrated Coastal Zone Management (ICZM) frameworks, (2) expanding the section on "Modelling Approaches and Applications" and (3) a discussion on scale issues relevant to indicator selection and use.

Our role as scientists in addressing this ToR is to provide science-based advice and recommended approaches for:

- characterizing ecosystem status and related aquaculture effects (e.g. effective indicator identification);
- identifying the potential consequences to coastal marine ecosystems from changes in this status (e.g. recommendations on thresholds of potential public concern);
- identifying effective measures for preventing or mitigating any impacts from shellfish aquaculture; and
- facilitating management decisions (e.g. decision-support tools).

This implies that we do not consider the consequences to industry or society stemming from our science-based recommendations. However, it is not solely the responsibility of ecological scientists to determine a framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone. Socioeconomic science considerations are also paramount in setting critical decision criteria (e.g. what constitutes an unacceptable impact?). Although socioeconomic issues were generally considered outside the scope of our activities, deliberations on many components of a pragmatic shellfish aquaculture management framework required discussion of costs to industry and "potential" public concerns. To help define what level of impacts are acceptable, socio-economical sciences may help in clarifying the values and expectations of different groups, and contribute to economic evaluation of environmental services. Furthermore, environmental conservation and protection and other legislations pertaining to the utilization of coastal areas in place within ICES countries are clearly important considerations for the selection of indicators, and particularly for the setting of management triggers/thresholds. These are reviewed in Section 4.6 in the context of Integrated Coastal Zone Management (ICZM) activities in many ICES countries.

This report is structured to address the topic by starting with general management approaches that consider all anthropogenic activities at the same level (ICZM). We then consider indicator-based management frameworks that deal with the concept of driving forces, impacts and responses, and impact assessment approaches and tools. More specific shellfish aquaculture management issues are then addressed, including identification of general and recommended indicators related to specific environmental, and to some extent socio-economical, effects from shellfish culture operations, potential applications of modelling, a discussion on thresholds of ecological and potential public concern, monitoring approaches for a diverse industry, impact mitigation measures, responsive management and decision support systems. The latter topics will be addressed by the WGMASC over the coming years.

4.2 New Developments in Integrated Coastal Zone Management (ICZM) Frameworks and their Effects on Shellfish Aquaculture

A selection of relevant legal and policy ICZM frameworks on the EU level and their potential effects on shellfish aquaculture operations in Europe were summarized based on an extensive review for the WGMASC meeting in 2007. Recent developments in these frameworks in 2008 were updated and are complied below. Additional expertise is needed within the WGMASC to review similar legislation and policies in North America. This may best be achieved through an appointment of an expert by the chair for participation in the next WGMASC annual meeting.

4.2.1 Selection of relevant legal frameworks on the EU level

4.2.1.1 Industrial Installations and the Integrated Pollution Prevention and Control Directive (IPPC)

The IPPC Directive is about minimizing pollution from various industrial sources throughout the European Union (EC, 1996). New installations, and existing installations which are subject to "substantial changes", have been required to meet the requirements of the IPPC Directive since 30 October 1999. The IPPC Directive is based on several principles, namely (1) an integrated approach, (2) best available techniques, (3) flexibility, and (4) public participation. In European Pollutant Emission Register (EPER), emission data reported by Member States are made accessible in a public register, which is intended to provide environmental information on major industrial activities. EPER will be replaced by the European Pollutant Release and Transfer Register (E-PRTR) from 2007 reporting period onwards.

***News*:** On 21 December 2007 the Commission adopted a Proposal for a Directive on industrial emissions. The Proposal recasts seven existing Directives related to industrial emissions into a single clear and coherent legislative instrument. The recast includes in particular the IPPC Directive. The IPPC Directive has been in place for over 10 years and the Commission has undertaken a 2 year review with all stakeholders to examine how it, and the related legislation on industrial emissions, can be improved to offer the highest level of protection for the environment and human health while simplifying the existing legislation and cutting unnecessary administrative costs. The results of this review have provided clear evidence of the need for action to be taken at a Community level.

The IPPC Directive has recently been codified (Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control). The codified act includes all the previous amendments to the Directive 96/61/EC and introduces some linguistic changes and adaptations (e.g. updating the number of legislation referred to in the text). However, t**he substance of Directive 96/61/EC has not been changed** and the adopted new legal act is without prejudice to the new Proposal for a Directive on Industrial Emissions.

***Implications for shellfish aquaculture*:** Since the substance of the Directive has not been changed, but streamlined, the implications for shellfish aquaculture remain the same: The IPPC Directive has the potential to simultaneously *affect* and *protect* aquaculture and fishery even beyond coastal waters. Large industrial installations have become more frequent along the coast. These installations are attracted by existing logistic opportunities (e.g. oil refineries, port facilities) or particular coastal resources. Shellfish operations are particular sensitive to pollution, which can result from these installations (e.g. Council Directive 79/923/EEC of 30 October 1979 on the quality required of shellfish waters as amended by Council Directive 91/692/EEC (further amended by Council Regulation 1882/2003/EC)).

URL: http://ec.europa.eu/environment/ippc/index.htm

http://eur-lex.europa.eu/JOHtml.do?uri=OJ%3AL%3A2008%3A024%3ASOM%3AEN%3AHTML

http://ec.europa.eu/environment/air/legis.htm#stationary

4.2.1.2 Global Monitoring for Environment and Security (GMES) and planned Directive for Spatial Information in the Community (INSIRE)

GMES is a joint initiative of the European Commission and the European Space Agency designed to establish a European capacity for the provision and use of operational information for Global Monitoring of Environment and Security (EC, 2004a). The GMES represents a concerted effort to bring data and information providers together with users to provide a better security against natural and man-made hazards through improved tools of prediction and crisis management used by civil security entities. In this context the planned INSPIRE Directive has to be seen (EC, 2004b; 2005b). It is a framework that shall establish a common platform for annotating and sharing geographic data between member states – a spatial data infrastructure. It emphasizes the *environmental* reasons to share data between official agencies in different EC countries.

News: On 10 October 2007, the European Commission presented its vision for an integrated maritime policy for the European Union. The vision document – also called the Blue book – was accompanied by a detailed action plan and a report on the results of the broad stakeholder consultation. The Blue Book outlines an integrated maritime policy for the Union, enabling it to adequately address the opportunities and challenges arising from technological development, globalization, climate change, and marine pollution, among others, which constitutes a landslide shift from the sectoral approaches practiced so far.

The Communication and accompanying Action Plan list a range of concrete actions to be launched during the mandate of this Commission. These actions cover a wide spectrum of issues ranging from maritime transport to the competitiveness of maritime businesses, employment, scientific research, fisheries and the protection of the marine environment.

GMES in the context of the maritime policy is seen as the essential element for the establishment of an appropriate marine data and information infrastructure (EMODNET: European Marine Observation and Data Network) which in turn should enable strategic decision-making on maritime policy, the expansion of value-added services, and sustainable maritime development. In particular, EMODNET based on GMES and integrated with GEOSS will serve to increase the precision of estimates of the magnitude and impact of climate change.

A second field of maritime policy where GMES is expected to play an important role is the monitoring of activities at sea ("maritime surveillance"), such as border control and traffic monitoring. As the member states and relevant agencies move towards more integration between the various systems engaged in or using maritime surveillance, new applications developed by GMES can be successively integrated.

Implications for shellfish aquaculture: The GMES system and the INSPIRE Directive has a clear connection to aquaculture. They provide valuable data and information which can be used in the development and implementation of aquaculture initiatives and their long-term monitoring. A good example for the cooperation between GMES and ICZM and the relevance for aquaculture is the European *Coastwatch* project. In this project, GMES is used to monitor coastal regions. The main focus is on the influx of landside pollution. The importance of the GMES has been reinforced by the Maritime policy initiative, which directly supports the safeguarding of shellfish cultivation operations.

URL: http://www.gmes.info/

and http://www.gmes.info/library/files/1.%20GMES%20Reference%20Documents/COM-2004-065.pdf

and http://inspire.jrc.it/

4.2.1.3 Summary

The main modifications occurred in the Industrial Installations and the Integrated Pollution Prevention and Control (IPPC) Directive and in the long-term regular and harmonised monitoring efforts by the GMES system and the INSPIRE Directive. The latter directive has seen momentum by the Maritime Policy initiative and may be regarded as a promising step towards comparable data and results on the European level. However, relevant parameters/indicators (also on economic and social indicators) still need to be identified. Relevant indicators for shellfish aquaculture should be incorporated in the regular monitoring programmes on the EU level, in which data collection and exchange should be improved.

4.2.2 Selection of relevant policy frameworks on the EU level

4.2.3 The Lisbon Strategy

The ten-year Lisbon Strategy, initiated in 2000, was devised by the EU as a commitment to bring about economic, social and environmental renewal in the EU. Under the strategy, a stronger economy shall drive job creation alongside environmental and social policies that ensure sustainable development and social cohesion. Several European and Environment Council meetings have called for an annual stocktaking on environmental integration into sectoral policies and a regular environmental policy review (commonly understood as the "Cardiff Process"). In February 2005, the European Commission simplified targets and reporting procedures, which resulted a single national action program for each country, and one EU growth plan. Although the Lisbon Strategy is mostly geared to improve European economic development and the labour market situation, it also focuses on environmental aspects. Reasonable development strategies in the field of protecting nature and combining economic and ecological aspects in a productive way are seen as key issues in the implementation of future policies.

News: There are minor improvements and developments like the Red Tape Website for business at Sep 21 of the year 2007. The EU Heads of States and Governments agreed to make the EU "the most competitive and dynamic knowledge-driven economy by 2010". Although some progress was made on innovating Europe's economy, there is nowadays growing concern that the reform process is not going fast enough and that the ambitious targets will not be reached.

In March 2008 The Spring Council, under the Slovenian Presidency, endorsed the priorities for the last 3 years of the Lisbon Agenda, laid out in the Commission's strategic report on the Lisbon Strategy. In autumn 2008 the Member states are going to present a second round of National Reform Plans, based on the revised integrated guidelines.

***Implications for shellfish aquaculture*:** Through the Lisbon Strategy, the protection of the environment is not approached as a singular issue, but is regarded as part of a coupled approach that also comprises the economic use of the coast. In this respect, aquaculture can be viewed as an option to generate alternative livelihoods in rural peripheral coastal regions in which the local labour market remains more or less dependant on coastal resources.

***URL*:** http://www.euractiv.com/en/agenda2004/lisbon-agenda/article-117510

and http://ue.eu.int/ueDocs/cms_Data/docs/pressData/en/ec/00100-r1.en0.htm (Draft)

and http://www.euractiv.com/en/future-eu/lisbon-agenda/article-117510

and http://www.euractiv.com/en/innovation/growth-jobs-relaunch-lisbon-strategy/article-131891

4.2.3.1 EU Cohesion Policy

The European Union's Cohesion Policy aims to redistribute wealth between richer and poorer regions in Europe in order to arrive at a more balanced economic integration and overall sustainable development. A number of different aspects that are covered by this policy, namely:

1) to achieve synergy effects in spatial planning
2) to address the spatial aspects of sectoral policies through intergovernmental and subregional cooperation structures
3) to provide access to and from central regions as well as from peripheral ones via transportation
4) to include sustainability in economic and spatial planning and as a possible source of synergy effects

The Cohesion Policy also offers opportunities to fund actions to mitigate or adapt to climate change.

News: There is a new EU Cohesion Policy and as from 2007, this policy will revolve around three new priorities or 'objectives:'

- **Convergence** (formerly Objective 1): support for growth and job creation in the least developed member states and regions. Regions whose per capita GDP is less than 75% of the EU average will be eligible (mostly regions from new member states), but temporary support (until 2013) will be given to regions where per capita GDP is below 75% for the EU-15 (the so-called 'statistical effect').
- **Competitiveness and employment** (formerly Objective 2): designed to help the richer member states deal with economic and social change, globalisation and the transition to the knowledge society. Employment initiatives are to be based on the European Employment Strategy EES (adaptability of the workforce, job creation and accessibility to the labour market for vulnerable persons).
- **Territorial cooperation**: to stimulate cross-border cooperation in order to find joint solutions to problems such as urban, rural and coastal development, the development of economic relations and the networking of SMEs. A new cross-border authority will be set up to manage cooperation programmes.

***Implications for shellfish aquaculture*:** In most cases, shellfish aquaculture takes place in rural peripheral areas (e.g. western Scotland, Galicia). The Cohesion Policy emphasizes investments in infrastructure, particularly in such Convergence regions, and asks the regions to comply with environmental legislation in the fields of water, waste, air and nature. Investments in sustainable energy and transport, as well as eco-innovation with clean technologies are also promoted in particular in remote and underdeveloped areas. The substantial experience gained from the Cohesion Policy for implementing the principles of subsidiary and partnership is very useful for developing win-win situations in coastal areas, i.e. aquaculture as means of generating alternative livelihood.

***URL*:** http://ec.europa.eu/regional_policy/sources/docoffic/2007/osc/l_29120061021en00110032.pdf

4.2.3.2 Maritime Green Paper

In March 2005 was the first step to work on a Green Paper for a future EU Maritime Policy. 2006 followed the adoption of these ideas.

News: In June 2007 the European Council has welcomed the wide debate that has taken place on Europe for the future Maritime Policy and this plan was eventually presented in October 2007 by the European Commission. Taking into account the principle of subsidiary the plan aims at exploring the full potential of sea-based economic activity in an environmentally sustainable manner. The Commission invites the EU Council, Council of ministers and The EU Parliament etc. to respond proactively to this policy.

Implications for Shellfish aquaculture: The integrated Maritime Policy for the EU offers scope and fresh prospects for an integrated planning system and management of aquaculture. ICZM will provide the link between the Maritime Policy, the Marine Strategy Directive with the sea on the one hand and the Water Framework Directive and other governing instruments of the land side on the other hand. This offers opportunities to promote a continuum of integrated planning and management of aquaculture.

URL: http://ec.europa.eu/maritimeaffairs/pdf/com_2006_0275_en_part2.pdf

and http://ec.europa.eu/maritimeaffairs/

and http://ec.europa.eu/maritimeaffairs/policy_en.html#com

4.2.3.3 Sixth EU Environmental Action Programme

The Environment Action Programme provides a strategic framework for the Commission's environmental policy up to 2012. The programme identifies four environmental areas for priority actions, also considering economic and social aspects:

- Climate Change
- Nature and Biodiversity
- Environment and Health and Quality of Life
- Natural Resources and Waste

The Sixth Environment Action Programme (6th EAP), which was adopted by the European Parliament and Council in 2002 and runs until 2012, requires the European Commission to prepare Thematic Strategies covering seven areas:

- Air Pollution (adopted 21/09/2005)
- Prevention and Recycling of Waste (adopted 21/12/2005)
- Protection and Conservation of the Marine Environment (adopted 24/10/2005)
- Soil
- Sustainable Use of Pesticides
- Sustainable Use of Resources (adopted 21/12/2005)
- Urban Environment (adopted 11/01/2006)

The Thematic Strategies represent the next generation of environmental policy and focus on identifying the most appropriate instruments to deliver European policy goals in the most cost-effective way.

News: The mid-term review of the 6th EAP was adopted by the Commission on the 30 April 2007. The mid-term review of the 6th EAP has confirmed that the Programme remains the correct framework for Community action in the field of the environment up to 2012.

Implications for shellfish aquaculture: The Thematic Strategies developed under the EU Environmental Action Programme are confined to a theme or sector. Several of these have direct links to aquaculture. They provide the opportunity to take up specific themes related to aquaculture operations and to bring its implementation into a wider context: from local, regional to national. It thus serves as an important vehicle to support and back up aquaculture operations.

URL: ec.europa.eu/environment/newprg/index.htm

and ec.europa.eu/environment/newprg/strategies_en.htm

4.2.4 Summary

The scope for streamlining shellfish aquaculture throughout the EU has increased by the introduction of the Maritime Policy and by the link of terrestrial/coastal (as stipulated by the Water Framework Directive). In both cases, an ecosystems-based management approach is either already in place or planned to be formed. During recent years the EU has made significant progress in devising policies with respect to encouraging the integration of sectors and the involvement of stakeholders and the wider public. As a case in point, the EU Cohesion policy aims to synergize economic and environmental concerns, especially taking local social-economic issues into account.

4.3 The use of indicators in the integrated evaluation of the impact of shellfish aquaculture

4.3.1 Definitions and concepts

A definition of the term "indicator" is based on Vos *et al.* (1985), as cited by Gilbert and Feenstra (1994), was explained as follows; "In measurement theory the term "indicator" is used for the empirical specification of concepts that cannot be (fully) operationalized on the basis of generally accepted rules". The function of indicators primarily lies in simplification, meaning that they are a compromise between scientific accuracy and the demand for concise information. Some examples of concepts for which indicators are used as surrogate measures include; ecosystem status, ecosystem health, environmental performance (also seabed or water-column performance), and functional sustainability performance (Rice, 2003, Gibbs, 2007). The indicators may be used for problem identification, planning, allocation of resources, policy assessment, etc. One of the important functions of indicators is that they can act as a bridge between science and policy. In this case the primary purpose will be for evaluating the shellfish culture system i.e. assessment of sustainability. Gilbert and Feenstra (1993) have on the basis of the literature identified four desired features of indicators:

- the indicator must be representative for the system chosen and must have a scientific basis;
- indicators must be quantifiable;
- a part of the cause-effect chain should be clearly represented by the indicator; and
- the indicator should offer implications for policy.

More detailed characteristics, or criteria, for desirable global sustainability indicators are given by Liverman *et al.* (1988).

Some concepts from the sustainability literature are worth remembering when assessing the relevance of indicators in a given context. Several authors have pointed out that an indicator cannot usually be made from a simple parameter. A chemical measurement or abundance generally does not prove to be effective indicator. For example, an isolated winter measurement of chlorophyll *a* is not relevant to indicate the local level of eutrophication (Bricker *et al.*, 1999), whereas an extreme statistic computed from data sampled at high frequency in an exposed site at risk season will better reflect this phenomenon. Thus, as stressed by Nicholson and Fryer (2002), the term "indicator" implies the relevance of the parameter, i.e., the linkage to the question or set of questions generating the need for the indicator(s). In the previous example, there is a direct relationship between chlorophyll *a* and coastal nutrient enrichment. The indicator-statistic, for example, a slope in Nicholson and Fryer (2002), and the associated metrics, i.e., the unit in case of a quantitative indicator, are necessarily parts of the indicator concept.

A parameter or set of parameters, or an "index" or a "score", are considered a good indicator only after it has been validated to effectively indicate what it was designed for. There are two nested conditions for this: (1) the appropriate mathematical approach must be defined that will transform quantitative or qualitative data into numbers that can be compared to threshold values in a predefined classification system; and (2) the information collection process (i.e. sampling design), consistent with the former condition, must be precisely defined to provide reasonable statistical power for effectively detecting an impacted area. Gibbs (2007), in his review of indicators for suspended bivalve culture, noted that the indicators should identify where present levels of culture may be in relation to; the ability of the culture to control phytoplankton dynamics, and to the ecological and production carrying capacity within the growing region.

4.3.2 The different indicator frameworks

Indicators are often presented within already established frameworks. Frameworks for the indicators produced are often built in a given social context (Olsen, 2003). They also depend on the spatial or economic scale considered (Spangenberg, 2002; Rochet and Trenkel, 2003). Using frameworks to present sets of indicators should be useful for the following reasons (Segnestam, 2002):

- Indicator frameworks provide the means to structure sets of indicators in a manner that facilitates their interpretation.
- Indicators are usually needed for many aspects of a problem or issue, and the framework selected ensures that all of those aspects have been taken into account.
- Frameworks can also aid the understanding of how different issues are interrelated.

Three different types of frameworks for presenting indicators are generally recognised (OECD 2000):

1) **Project-based frameworks** (also referred to in the literature as the Input-Output-Outcome-Impact framework), which are used in the monitoring of the effectiveness of projects whose objective it is to improve the state of the environment.

2) **Driving Forces–Pressure-State-Impact-Response (DPSIR) frameworks** originally developed by the Organisation for Economic Cooperation and Development (OECD) for national, regional and international level analyses, and are now in use in the European Environment Agency (among other international institutions).

3) **Frameworks that are based on environmental (or sustainable development) themes** (e.g. Pelagic/benthic; communities and species; flows of carbon/nitrogen; loss in diversity; economic damage; intensive vs. extensive aquaculture; open or closed environments; hydrodynamics…)

4.3.2.1 The DPSIR frameworks

The DPSIR framework (Figure 4.1) is becoming widely used, as it allows coverage of a large spectrum of particular situations, as long as the environment is concerned. This framework was originally derived from the social studies and has subsequently been widely applied internationally, particularly for organising systems of indicators for managing environment and sustainable development. A full description is given by the Organisation for Economic Cooperation and Development (OECD). The first version of this framework is called the Pressure-State-Response (**PSR**) framework that states that human activities exert *pressures* on the environment, which can cause changes in the *state* of the environment. Society then *responds* with environmental and economic policies and programs intended to prevent, reduce or mitigate pressures and/or environmental impact.

The first variation of the PSR framework replaces the pressure indicator category with a category of driving force indicators, creating a Driving Force – State – Response (**DSR**) framework. The driving force component includes human activities, processes and patterns that impact on sustainable development, and is intended to better accommodate socioeconomic indicators. The second variation adds a category of impact indicators, transforming it into a Pressure-State-Impact-Response (**PSIR**) framework. The latest version, which has become widely employed, is the **DPSIR** framework. In this framework, the Driving forces, produce Pressures on the environment, which then degrade the State of the environment, which then Impacts on human health and eco-systems, causing society to Respond with various policy measures (Figure 4.1). When producing a set of indicators related to the impact of shellfish farms, most of these indicators will probably be related to the State and Impact categories.

4.3.2.2 Other frameworks relevant in assessing the Impact of shellfish aquaculture on marine environments

Considering the impact of aquaculture on marine environments, a framework based on the type of shellfish culture, may be relevant. Also of interest is an ecosystem based framework, which is best utilised when considering the need for an ecosystem approach. To cope with the particular aspects of the impact of shellfish culture, it is suggested that an environmental framework includes the following themes, which correspond to the main impacts observed in marine environments:

- impact on seabed geophysical properties, geochemical processes and the structure and ecological role of benthic flora and fauna (i.e. indicators of seabed status and benthic performance),
- water-column interactions with shellfish culture (i.e. effects on water quality and pelagic ecosystem structure and function),
- the cumulative ecological effects of any pelagic and benthic interactions with shellfish culture,
- potential genetic implications of culture activities,
- the synergistic and/or antagonistic effects of all anthropogenic activities in the region, and
- socio-economics aspects.

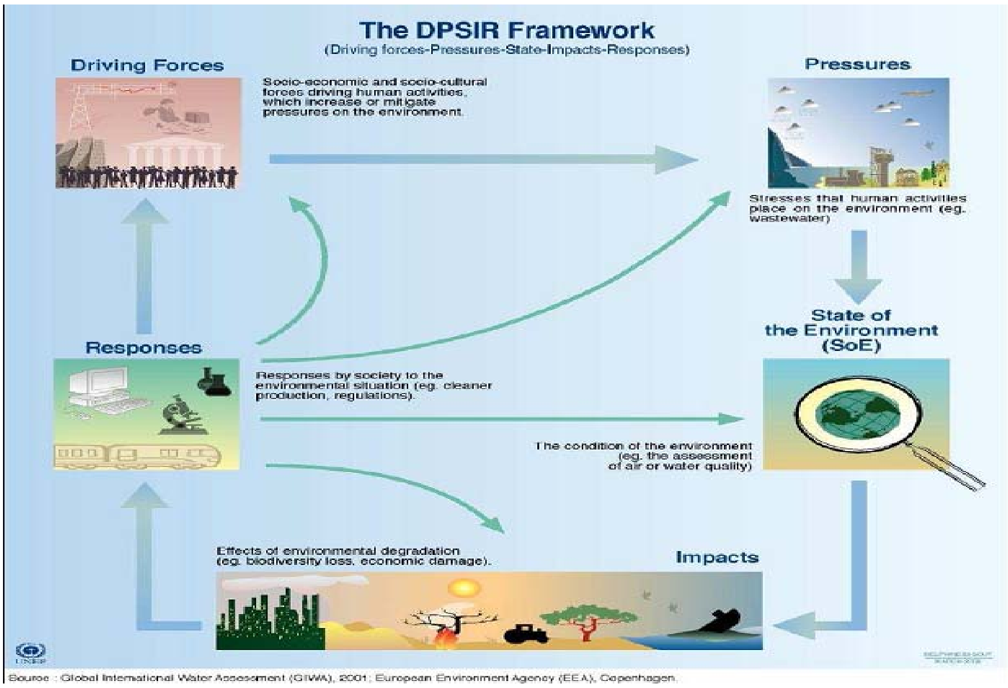

Figure 4.1. Schematic diagram of the DPSIR framwork.

4.3.3 Slow and fast variables as indicators

There are "fast" and "slow" variables that can be employed as indicators of the effects of shellfish aquaculture on marine ecosystems. Slow response variables are frequently important driving forces for dynamic interactions in an ecosystem (e.g. semi-enclosed estuaries with little tidal range versus oceanic conditions), while fast variables describe component dynamics that iterate more rapidly (e.g. phytoplankton growth). Slow variables, such as currents and residence time in a water body, provide the context for the dynamic interactions of fast response variables of a system. Component relationships between these types of variables (i.e. between ocean currents, productivity and production output of shellfish) have to be integrated to capture intrinsic local-specific properties. A number of conditions and processes among the slow variables act as basic drivers of change. For instance, while ocean currents are not inevitably persistent, they certainly condition the initial direction of economic, social and environmental change and may strongly influence even the long-term future. However, unlike fast variables, the slow variables often are not easily manipulated for management purposes. For both types of variables, it is important to describe the relationship of all indicators to the functioning of the ecosystem and the type(s) of shellfish aquaculture operation.

4.3.4 Linking indicator frameworks across geographical scales in integrated shellfish cultivation assessments

Indicator systems are seen as central tools for ecosystem-based fisheries management, helping to steer fisheries towards sustainability by providing timely and useful information to decision-makers. Without testing hypotheses about the links between policies and outcomes, however, indicator systems may do little more than promote *ad hoc* policies, possibly even prolonging the transition to sustainable (shellfish) fisheries (Rudd, 2004). Ideally, the indicator framework for integrative shellfish cultivation assessment should transparently encompass both driver-oriented pressure-state-response (**DPSIR**) frameworks and structurally oriented sustainable livelihood indicator frameworks, thus providing a platform for ecosystem-based fisheries management policy experiment design and monitoring.

4.3.4.1 Integrated shellfish cultivation indicators as part of social-ecological system analysis

Over the past decades, scientists and policymakers have become increasingly aware of the complex and manifold linkages between ecological and human systems, which generated a strong research effort into social-ecological systems analysis. Social-ecological systems are understood to be complex adaptive systems where social and biophysical agents are interacting at multiple temporal and spatial scales (Janssen and Ostrom, 2006). This has stimulated researchers across multiple disciplines to look for new ways of understanding and responding to changes and drivers in both systems and their interactions (Zurek and Henrichs, 2007). Integrated coastal zone management (ICZM) and integrated shellfish cultivation can be viewed as being part of this social-ecological system paradigm, in which special emphasis is placed on the complexities of coastal settings and their manifold drivers in ecological and human systems.

By addressing the interactions and feedbacks between issues (e.g. economic, social and environmental consequences) it becomes evident that many of these play out over time (i.e. in past, present and future contexts) and space (i.e. at local, regional and ecosystem/global scale)—these are referred to as ‘cross-scale’ or ‘multi-scale’ processes. To take account of this array of complexity in the context of decision-making, a number of research supported approaches to indicator and monitoring systems have been developed and advanced to better understand the current and future interaction of various driving forces (Carpenter and Brock, 2006). Recently indicator systems have also been used to address multi-scale processes or to link social-ecological systems developed at various geographical scales with each other in order to better understand the interaction of processes, objectives and institutional arrangements across scales (Carpenter *et al.* 2008, WGICZM 2008).

Processes at different geographical scales, however, commonly unfold over different time scales: The more aggregated the geographical scale (e.g. the regional ecosystem scale), the slower a system's dynamics unfold. Conversely, at a less aggregated geographical scale (e.g. the local scale) the social-ecological dynamics are more responsive. Thus, in a hierarchical system, the more aggregated level can be seen to set the boundary conditions for any lower level of aggregation (Zurek and Henrichs, 2007). Thus, larger scales are required to understand the *context* in which an indicator works and the smaller scales support our understanding of the underlying *mechanisms* of the respective indicator. The level of interconnectedness across scales varies and depends largely on the approaches used to develop multi-scale indicators.

4.3.4.2 Scale issues of indicators

As our frame of reference, we distinguish two levels of indicators across scales: (a) scale-dependent indicators that require a certain scale of perception to make them appear in a certain way and (b) scale-independent indicators which do not change their qualities when perceived on different scales. Which indicator is best suited and how much interconnectedness is needed, will depend both on the focal issue and the primary purpose of the indicator, i.e. whether the aim is scientific exploration or decision-support for management (of shellfish aquaculture). This cannot be decided by science/ICES alone but is related to the respective social and policy arena of the ICES member states. The latter acts as the key denominator for the definition and local acceptance of thresholds for the respective indicator, since they reflect the basic overarching logic of local/regional decision-making and their respective societal values. Thus, indicators need to be site specific and measurable and relevant at local levels and political realties, in order to gain local acceptance and achieve practical application.

Commonly, indicators for shellfish cultivation are built around a set of driving forces and focus on processes at a specific geographic scale that shape the shellfish aquaculture development. This includes the locally-rooted decision-making context in which it operates, since the application of certain indicators and their respective thresholds for shellfish cultivation may differ between countries and between regions due to differences in needs, traditions, cultures or management systems. More recently, indicator approaches have also been used to address multi-scale processes and to link repercussions at various geographical scales with each other to understand more fully the cross-scale interactions of shellfish cultivation. For example, geochemical parameters indicating reductions in benthic community diversity inside mussel farms in Tracadie Bay, Canada, (Hargrave *et al.,* in press) go hand-in-hand with observations of local and bay-scale phytoplankton depletion (Grant *et al.* 2008), the attraction and increased productivity of some demersal fish species (WGEIM, 2006), potential impacts of mussel biodeposition on ecosystem energy flow and nutrient cycling, and cumulative interactions between the benthic and pelagic effects of aquaculture and coastal eutrophication from land-use (Cranford *et al.* 2007). This integrate, multi-scale approach allows, for example, specific decision units (be it an individual, a company, an organisation or even a country) to think about implications of shellfish cultivation in a wider decision context. This context is usually outside the immediate sphere of influence of the decision unit itself, yet sets the boundary conditions and highlights the respective dependencies against which any decision needs to be taken.

In a multi-scale indicator concept, not all indicators on one subject are relevant to other subjects and to other scales. Therefore, one can distinguish between *intermediate indicators* and *end indictors* for a respective geographical and temporal scale. Figure 4.2 is a schematic sketch on this distinction.

Within the WGMASC, there had been a considerable effort to compile a list of relevant bio-geophysical indicators (see below). These cover a wide range of intermediate and end indicators on various levels, including a review on the relevant legislative and policy framework in the EU in which shellfish cultivation and the monitoring of key indicators may take place. In a next step, these should be integrated with the social and institutional indicators of other ICES working groups, namely with those developed (or are in the stage of being developed) by the WGICZM (see recommendations of ICES report WGICZM 2007). Such an integration of EG activities may be best accomplished within a cross-cutting ICES Science Program that includes members from multiple expert groups.

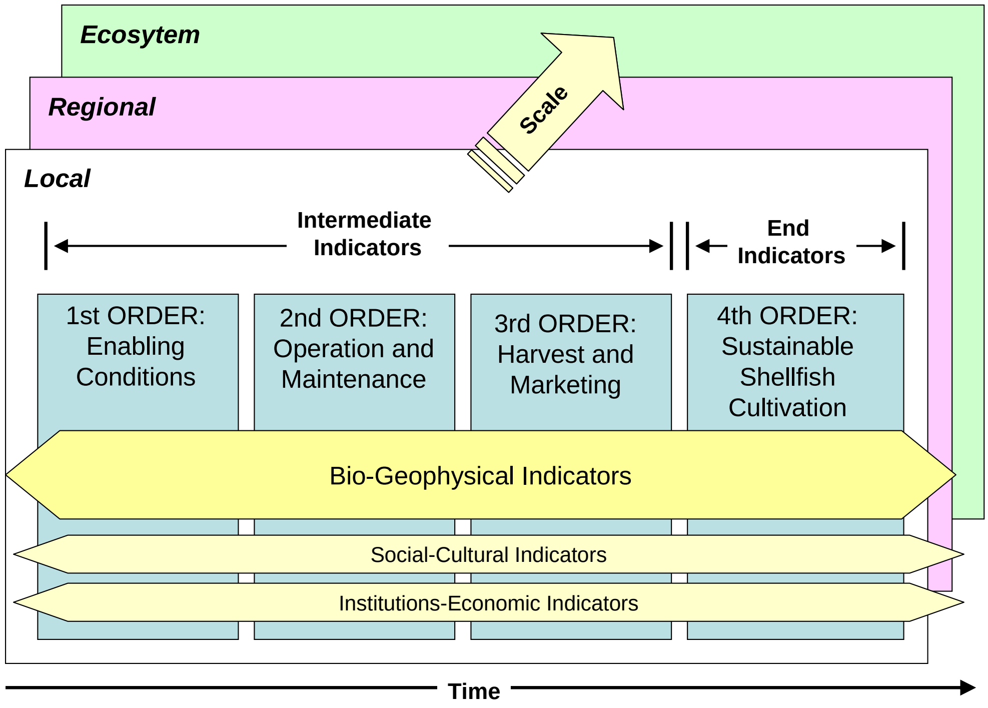

Figure 4.2. Schematic of the multi-scale indicator concept based on a natural science/shellfish operation point of view. A similar approach, with different indicators, may be established to focus on social science.

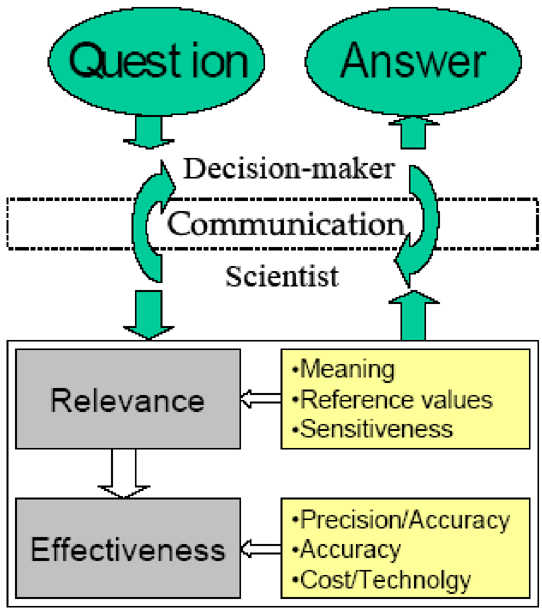

Figure 4.3. Criteria to be considered in choosing environmental or ecological indicators (from (Nicholson and Fryer, 2002).

4.3.5 Assessment of indicators

Not one universal set of indicators is applicable in all cases (Segnestam, op.cit.). However a small set of well-chosen indicators tends to be the favourite choice of most indicators users, including the stakeholders for aquaculture. A number of selection criteria can be applied when there is a need to restrain the number of indicators. Several recent papers have proposed a list of performance criteria for environmental or ecological indicators (Kurtz, Jackson *et al.* 2001, Rice, 2007) and specifically for fishery indicators (Garcia and Staples 2000) and shellfish aquaculture (Cranford *et al.*, 2006; Gibbs, 2007). Rationale is presented in the following sections for the presentation of indicators based on relevance and effectiveness (Figure 4.3; Nicholson and Fryer, 2002), as well as on other characteristics.

4.3.5.1 Relevance

For all authors, the relevance or meaning of an indicator represents the first essential phase in the process of indicator selection. There should be a clear or understandable linkage between the indicator and the objective, i.e., what it is supposed to describe? For example, species richness or the number of species by taxonomic group has often been used as an indicator of biodiversity.

4.3.5.2 Effectiveness

This criteria is defined as the indicator ability to respond to variations in forcing, i.e., in pressure. While some indicators may respond to dramatic changes in the system, a suitable indicator displays high sensitivity to particular and, perhaps, subtle stress, thereby serving as an early indicator of reduced system integrity (Dale and Beyeler, 2001). Most reference points for population indicators are estimated with unknown precision, and no reference points are available for any of the community indicators.

4.3.5.3 Precision/Accuracy

Precision, or in an opposite way variability, is referred to as robustness by Garcia and Staples (2000). According to these authors, an indicator is considered to be robust if results are not too variable with regard to random (e.g., between-individual responses) or pseudo-random (e.g., hydro-climatic factors) fluctuations.

4.3.5.4 Feasibility

Trade-offs between desirable features, costs, and feasibility often determine the choice of indicators (Dale and Beyeler, op.cit). Theoretical indicator constructions are useless on an operational basis if adequate data are not available, either due to the fact that the data are technically a very difficult if not impossible challenge to obtain or collecting the necessary information is too expensive.

4.3.5.5 Sensitivity

A good indicator is expected to be both sensitive and precise. Ideally, the indicator has a known substantial response to disturbances, or anthropogenic stresses, and changes over time, and has low variability in response. Monitoring programmes often depend on a small number of indicators and, as a consequence, fail to consider the full complexity of the system (Dale and Beleyer, op.cit.). This is most important for ecological indicators that address the complexity of ecosystems.

4.3.5.6 Clarity

For the same authors, clarity by managers or more generally non-scientists is proposed as an element of indicator selection. Still, the world of indicators seems to be open to conceptual and methodological developments. Progress could be achieved in the use of extreme statistics instead of median or average values, and in the development of methods to combine indicators to improve decision-making.

4.3.5.7 Other

The following list of the criteria proposed by the OECD (OECD, 2000) and ECASA partners, can be used for the evaluation of the different indicators related to the impact of shellfish culture on the environment:

- direct relevance to objectives and the target group,
- the indicator selection must be closely linked to the environmental problems being addressed,
- different target groups could have different needs and uses for the information provided by the indicators. Consideration of who the target group consists of is therefore central, and
- clarity in design.

It is important that the selected indicators are defined clearly based on the following criteria to avoid confusion in their development or interpretation.

- *Realistic collection or development costs*. Indicators must be practical and realistic, and their cost of collection and development therefore needs to be considered. This may lead to trade-offs between the information content of various indicators and the cost of collecting them.
- *High quality and reliability*. Indicators, and the information they provide, are only as good as the data from which they are derived.
- *Appropriate spatial and temporal scale*. Careful thought should be given to the appropriate spatial and temporal scale of indicators.
- *Obvious significance*. Such a criteria may overlap with the one on "clarity in design", but one should remember that the final uses of indicators are those of communication tools. Their significance should easily be understood by stakeholders. According to this criterion, the layman should retain the simplest concept and/or presentation for a better comprehension. For example, indicators on levels of oxygen are better understood then those on sulphide concentrations. When possible, the data should be presented quantitatively (0–10 or 0–100, or % saturation O_2).
- *Responsive*. For an ecosystem approach to management to be effective, the time-frame between indicator data collection and the decision-making process needs to be as short as possible. Responsive and adaptive management approaches strive to implement mitigation measures quickly so that ecosystem status does not continue to deteriorate. Near real-time indicators therefore have a distinct advantage in such programs, whereas indicators that require considerable work to process samples and interpret data may be less desirable.

4.3.6 A list of potential Indicators

Indicators describing the impact of shellfish aquaculture on the coastal zone and on the ecosystem status were compiled from different sources. Several European contracts were aimed at producing indicators related to the interaction of aquaculture (and shellfish culture) with the marine environment. Examples of attempts to compile indicators related with the sustainable development of marine aquaculture include the *MARAQUA* (www.lifesciences.napier.ac.uk/maraqua/), *Consensus* (www.consensus.org) and *ECASA* (www.ecasa.org) programs. The 2006 Canadian review of potential indicators and associated thresholds aimed at the assessment of shellfish aquaculture impacts on fish habitat has been useful because of the pertinence of the ecosystem approach used (DFO, 2006; Cranford *et al.*, 2006; Chamberlain *et al.*, 2006). The review by Gibbs (2007) focuses on sustainability performance indicators based on bivalve aquaculture interactions in the water-column (e.g. clearance efficiency, filtration pressure, regulation ratio and depletion footprint).

The culture of bivalve molluscs and their associated rearing structures has the potential to impact the environment in positive and negative ways (might be placed in introduction). The identified effects are generally referred to the consumption of suspended particles, to the increased sedimentation due to the production and release of biodeposits which impacts the sediment biogeochemistry, to the nutrient cycling, and to the structure and composition of the benthic and pelagic communities. These impacts are related to the basic interaction of bivalves with their environment, as illustrated in Figure 4.4.

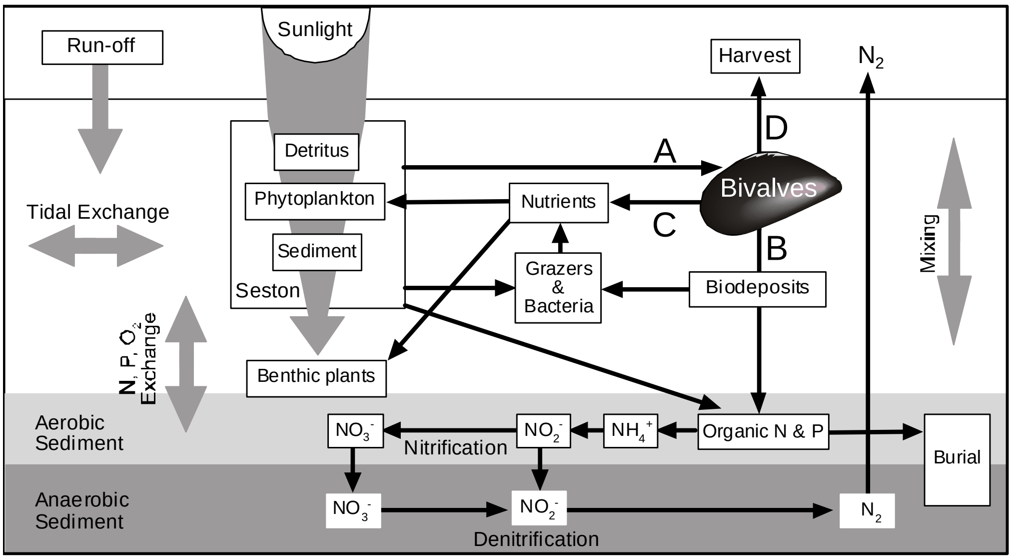

Figure 4.4. Conceptual diagram of shellfish (bivalve) aquaculture interactions in coastal ecosystems related to: (A) the removal of suspended particulate matter (seston) during filter feeding; (B) the biodeposition of undigested organic matter in faeces and pseudofaeces; (C) the excretion of ammonia nitrogen; and (D) the removal of materials (nutrients) in the bivalve harvest (from: Cranford *et al.*, 2006).

Recommending the use of ecosystem status indicators specific to shellfish aquaculture should be considered in the perspective of a wider ecosystem approach of the shellfish culture. An ecosystem approach may be defined as 'a comprehensive integrated management of human activities based on the best available scientific knowledge about the ecosystem and its dynamics, in order to identify and take actions on influences that are critical to the health of ecosystems, thereby 'achieving sustainable uses of ecosystem goods and services and maintenance of ecosystem integrity' (Rice *et al.*, 2005). Documenting the impact of shellfish culture on the marine environment through the use of indicators is part of such an ecosystem approach, and should be completed with the implementation of recommendations on specific management methods, on assessment, monitoring and scientific research, and on methods of measuring progress towards implementation.

4.3.6.1 Impacts of shellfish culture on the benthic habitat and communities

Benthic impacts are well known as they are spatially limited, and easy to monitor and assess with the current sampling and analytical techniques. They are related to the production of bivalve faeces and pseudofaeces that fall on the sediment + sedimentation due to structures slowering currents. As the biodeposits contain organic matter (15 to 50%), they produce both an increase in the silt content and an organic enrichment of the seabed. The degree of organic enrichment and the resulting impact is site specific, depending on interacting factors, including the hydrodynamics of the system, water depth and residence time, the reared biomass and phytoplankton dynamics.

4.3.6.1.1 Sediment indicators

The main impacts on the sediment are related to the sedimentation of shellfish biodeposits, the resulting accumulation of organic matter, and its mineralization. Some indicators intend to characterise the change in the sediment properties, others address the flux of organic matter to the sediment, and other indicators describe the biogeochemical processes associated with the ecological recycling of the organic matter:

- *Sedimentation rates* as measured by sediment traps. The sediment traps facilitate measurements of the quantity and quality of particulate matter falling from shellfish culture, both in subtidal and intertidal environments. Probably the simplest measurement of the impact of shellfish culture consists of collecting the biodeposits produced by bivalves during a given amount of time. This is a measure of flux of sediment and organic matter to the seabed.
- *Sediment texture* (percent sand-silt-clay) of the sediment is directly influenced by the bivalve culture. The particulate matter is either aggregated as pseudofaeces by the gills of the molluscs or egested as faeces which contain a significant amount of mineral particles.
- *Total organic carbon* in the sediment reflects the amount of organic matter within the sediment, a major part resulting from the biodeposition observed under the bivalve culture. This is usually measured in surface sediment.
- *Total nitrogen* and organic nitrogen in sediment.
- *Sediment carbon quality indicies* including % carbon (inorganic-organic matter), C:N ratio and the Rp index. This Rp indicator (Kristensen, 2000) is based on the ratio of a measure of the labile organic carbon, as estimated by the losses on ignition a t 250°, and a measure of the refractory organic matter, after ignition at 500°C, and seems to be sensitive to the molluscs biodeposition (ECASA results).
- *Redox and Eh in surficial sediment*. Low values of the redox potential are linked with the anaerobic degradation of the organic matter into the sediment. It is best measured through vertical profiles into the sediment, which allows the thickness of aerobic and anaerobic conditions to be determined, as related with the quantity of organic matter.
- *Total sulfides* in surface sediment, which is related to oxygen content and biodiversity (Hargrave *et al.*, 2008).

- *Dissolved oxygen consumption* rate in sediment is a measured of the degradation of the organic matter in the upper, oxic layers.
- Other measurements can be performed on the *pore water gradient* of mineral, dissolved nutrients produced during the oxidation process, such as Ammonia, total nitrogen, total phosphorus, and sulphates.
- *Benthic/pelagic fluxes* of sulfate and ammonia.
- *Trace metals* in sediment under finfish farms have been observed to increase. As these products seem to originate from the food, their pertinence in the case of bivalve culture needs to be demonstrated.
- Some *biomarkers* are candidates as indicators of the impact of shellfish culture. (Biesen and Parrish, 2005) have shown that the mono-unsaturated fatty acid content is higher in sediment beneath fish farm. Again, this needs to be demonstrated in the case of bivalve culture.
- The *chlorophyll pigments in surficial sediment* can be investigated as an indicator of the impact of shellfish farms in low energy environments. A fraction of phytoplanktonic cells is not digested by the bivalves and can accumulate beneath the facilities.
- *Nitrifier and denitrifier bacteria* population abundance and activity.
- *Sediment profile imaging*. Vertical profiles images sediment beneath aquaculture operations shows changes in sediment colour and organism distributions indicative of organic enrichment effects.

4.3.6.1.2 Benthic communities indicators

The changes of the texture and biogeochemical properties of the sediment result in a modified habitat, and the ecological communities are reacting to these changes. The biomass can be affected. Sometimes biomass may increase because of the input of organic matter, but it can also decrease when higher organic input, resulting from stress on different species. Ecological diversity can also be affected, and a reduction in the number of species may be observed according to the conceptual scheme established by Pearson and Rosenberg (1978).

The most basic community indicator consists of observations of the presence/absence of macrofauna under the shellfish installations. A total absence of benthic species under shellfish culture has never been reported. Therefore, this indicator does not seem to be of interest for the impact assessment of shellfish culture. Various diversity indices are classical in describing the ecological diversity among communities (Shannon-Wiener index, Margalef index, species richness, Pielou'Evenness, Abundance and biomass, Number of species, A/S, B/A). Sometimes, they can fail in revealing the structure of communities submitted to heavy organic load from mussels' farms (Grant *et al.* 1995). However these indices may still be used in many cases to characterize the impact of shellfish aquaculture.

Some diversity indicators have been proposed to describe the change in biodiversity occurring under the shellfish culture, and are under test, notably within the course of the ECASA project:

- Macrofauna multivariate indicators intend to classify the different species according to their contribution as revealed by a canonical correspondence analysis,
- The meiofauna diversity indicator is under test by the research teams involved in ECASA.

- A size-related indicator has been proposed. It relies on the fact that most of the species tolerant to an organic enrichment belong to families such as the Spionidae, and have a small size. Therefore a differential sieving of the sediment sampled for macrofauna studies, on 1 mm and 0.5 mm sieves, would allow quantification of the relative part of the smaller individuals into the whole community.
- Indicators based on the relative proportion of ecological groups among a community have also been proposed. The AMBI indicator has been tested in various environments and polluted sites. While it is not specific to aquaculture impact, it proved to react properly in the presence of organic enrichment in a manner very similar to those resulting from shellfish culture in confined areas.
- Indicator species or bioindicators are useful in heavily impacted communities. *Capitella capitata* is an opportunistic species that dominates or replaces the other benthic species in the presence of high levels of organic matter, and is distributed almost worldwide. Other species less tolerant to the organic enrichment can also be found in enriched areas, but they may not have the same wide distribution. Therefore, a dominant population of *Capitella capitata* may be considered as a good indicator of strong impact of shellfish culture due to heavy loads of organic matter on the sediment.
- Trophic indices are related to the consequences of the organic enrichment into the sediment. It is generally observed that this would favour deposit feeders and scavengers, at the expense of filter feeders. The infaunal trophic index ITI, and the definition of benthic trophic groups have been selected by the ECASA group to be representative of the impact caused by shellfish aquaculture on the trophic characteristics of the macrofauna.
- Sensitive habitats, or sensitive and endangered species (mammals, birds, endangered species) as identified in European union directives and national rules, should be protected from the impact of aquaculture facilities. Shellfish culture does not potentially harm the migratory birds, as long as their feeding territories and their nesting areas are far enough from the human presence. Practically, this results in the exclusion of shellfish culture from these areas, and the presence of these sensitive habitats and species constitutes an indicator of the impact of shellfish culture.
- The use of video monitoring of the sea bed under and at the vicinity of aquaculture facilities also allows indicators to be calculated using image processing and statistical analysis. An example of this is given by Bugden (1998), where the bacterial mats produced in anoxic surface sediments can be tracked by video analysis.

4.3.6.2 Impacts on pelagic population dynamics, community structures and nutrient dynamics

Shellfish aquaculture, under some conditions (largely related to hydrodynamics and shellfish stocking density), has been shown to alter many biological and chemical properties of the water column that control ecosystem structure and function. Owing to the movement of the water, these effects can be transported far-field, with a measurable impact at the coastal ecosystem scale (Cranford *et al.*, 2006, Gibbs, 2007). Several pelagic indicators have been proposed to describe the change in biodiversity occurring under the shellfish culture:

- Rapid synoptic surveys of the *phytoplankton biomass (chlorophyll a) depletion* footprint, resulting from bivalve grazing, reveal phytoplankton depletion at the farm to bay scale (Cranford *et al.*, 2006, Gibbs, 2007 and references cited therein). This pelagic status indicator is also relevant to bivalve induced depletion of, and competition with, the zooplankton.
- *Shift in plankton size spectrum*: A potential consequence of size-selective food particle depletion by cultured shellfish is a significant change in the size structure of the microbial plankton community from larger phytoplankton to smaller picophytoplankton. Given the potential ecosystem consequences of a shift in the pelagic foodweb, indicators of size spectrum changes (e.g. increased picoplankton abundance and proportion of phytoplankton; increased bacteria counts) are perceived as being highly beneficial for use in monitoring programs in extensively leased shellfish aquaculture inlets Cranford *et al.*, 2006). This recommendation was also related to the relatively low cost of analysis, the ease of data interpretation, and the fact that site-specific measurements of plankton community alterations generally reflect conditions over much larger scales of impact.
- A greater *abundance of naturally occurring bacteria* can occur due to remineralization of organic matter in shellfish biodeposits and consumption by shellfish of some fraction of the natural planktonic grazer community.
- *Nutrients concentrations*: There is ample evidence to link shellfish aquaculture to coastal nutrient dynamics. However, the use of nutrients as indicators of bivalve culture impacts is challenging owing to the high natural short- to long-term variability in nutrient concentrations in coastal systems. Other pelagic indicators (e.g. phytoplankton abundance and productivity and shellfish growth) may act as suitable proxies for detecting impacts on nutrient dynamics.
- *Dissolved oxygen (DO)* measurements are relevant to a wide range of aquaculture/ecosystem interactions and are therefore potential indicators of ecosystem status.

4.3.6.3 Quantifying shellfish stock and production

Shellfish performance indicators (growth, condition index, etc.), similar to bulk particle depletion measurements (below), do not reveal information on specific changes in the structure and functioning of ecosystems, but provide an indication as to whether shellfish aquaculture is affecting the system to a greater extent than can be absorbed by natural processes. Particle depletion and shellfish performance measurements are highly complementary, as the former provides information on food supplies that likely control the latter.

- *Caged bivalves.* A major strength is that standardized shellfish performance measures are relatively inexpensive to perform. However, if there is large spatial and temporal variability in environmental conditions (particulate food supplies) in the farmed region, the performance of the caged shellfish will be site specific. Although the use of caged bivalves as indicators of ecological performance has potential, the interpretation of the results requires complementary information on a wide range of variables that can affect bivalve growth (temperature, currents, food abundance and nutritional quality, salinity, etc.), thereby decreasing the practicality of this approach (i.e. difficult interpretation).

- *Time series of farm stocking and production* have proven useful as indicators of growth conditions within extensively leased mussel aquaculture inlets (Cranford *et al.*, 2006). Long-term trends in total shellfish production (e.g. average mussel and oyster yield per culture unit) have been used to assess the effects of increasing stocking density on bay-wide aquaculture production (Héral, Bacher *et al.*, 1989). These data are generally collected for aquaculture operations and are critical for facilitating the interpretation other indicator results (e.g. phytoplankton depletion, benthic indicators), and as a general indicator for assessing bay-scale ecological performance/status.

4.3.7 Critical open issues related to indicators

From our view, several critical issues in multi-scale indicator systems remain to be tackled. Maybe the most prominent one that surfaced in the discussion in the WGMASC in 2008 pertain to the problem of scale and units of a specific indicator. Some of these open issues are listed in the bullets below and will require more attention by the WGMASC in the next meeting in 2009.

a) Identify appropriate geographical/spatial scale and boundary:
- Which institutional unit (local, regional, national level)?
- Which social unit (local fishermen; cooperatives; communities)?
- Which ecological unit (trophic cascades; ecosystem; embayment)?

b) Identify appropriate temporal scale:
- At what time scale does variance of an indicator leads to ecological transition (e.g. indication of a regime shift)?
- What is an appropriate return rate after perturbation?
- Degree of frequency of key ecosystem indicators sampling?
- Local institutional changes occur on which scale?

c) Identify the baseline (terms of reference) of indicators for a given area:
- How to achieve a local participative consensus on what is the “desired” state which is reflected in a certain value of the indicator?
- Focus on the legislative framework as guide for indicators?
- Sufficient to generate a science-based definition of a baseline of an indicator?
- Who makes assumptions regarding what comprises sustainability and how are they reflected in the indicator and its threshold?

Questions relating for instance to how market, government and civil society organizations use strategic investments in capital assets and institutions to achieve sustainability objectives for shellfish cultivation are, however, beyond the scope of the WGMASC.

4.4 Modelling approaches and potential management role

Modelling is often used as a tool to predict probable changes in environmental indicators/parameters. Models have been used to describe our understanding of environmental processes at work at farm to regional spatial scales and vary greatly in complexity from simple scaling exercises that compare flushing times to clearance times (e.g. Dame food depletion index), energy or nutrient budgets, simplified to complex 2-D box models and 3-D finite element models coupled with hydrodynamic models. Many models focus primarily on shellfish crop production and the influences of hydrodynamics, food availability and production, bivalve feeding physiology, and stocking density. The ability to predict the shellfish production carrying capacity for shellfish aquaculture is therefore well developed and has been applied in a wide range of ecosystems (reviewed by McKindsey *et al.,* 2006). Such models also provide information on some other community and ecological effects associated with any negative feedback on the culture.

The ECASA project has identified a virtual toolbox containing, among other 'tools', a list of models such as ShellSIM, FARM, Longlines, DEB, and DDP, that can be used by operators and public environment managers to minimize the environmental impact from shellfish aquaculture operations, to help maintain environmental quality and ensure the sustainability of sites and water bodies for aquaculture (www.ecasatoolbox.org.uk). To date, the majority of these shellfish models have been concerned with optimizing production rather than with the environmental impact of bivalve farming

The zone of potential benthic community effects from shellfish biodeposits may be predicted using particle tracking models that predict organic matter flux to the seabed (Chamberlain, 2002). Similarly, the potential ecological effects from mussel culture may be predicted using data-intensive nitrogen budgets, spatially explicit food depletion models and ecosystem models of varying complexity (Cranford *et al.,* 2007, Grant *et al.,* 2008). A study using a mass-balance approach and the ECOPATH model concluded that the ecological carrying capacity of the study area, as indicated by the shellfish production level causing major changes in energy fluxes within the system's food web, occurred at production levels that are considerably less than those that exceed the production carrying capacity (Jiang and Gibbs, 2005). This is in general agreement with results presented by Cranford *et al.*(2007) who used a nitrogen budget and results from lower trophic level box model scenarios to demonstrate the dominant role of extensively cultivated mussels in controlling ecosystem functioning (Cranford *et al.,* 2007). Ecosystem models have also been used to test scenarios of changes of aquaculture pressure on water quality (Nobre *et al.,* 2005) and ecosystem productivity (Marinov *et al.,* 2007) within the DPSIR methodological framework.

In practice, it is often impossible to use indicators to measure ecological conditions at a site prior to the initial development of shellfish culture. The ability of models to estimate the difference between the observed situation in the presence of shellfish activity and the expected situation without the activity, within an expected level of confidence, is a potential solution to this management problem and provides discrimination between the suspected causative factor (shellfish culture) and other factors.

Fuzzy logic approaches (such as applied by SIMCOAST™) are capable of combining modelling approaches and their respective sets of indicators. This supports the management of shellfish aquaculture under conditions of uncertainty. All the modelling approaches are constantly and rapidly evolving. They are useful to identify indicators of ecosystem status and associated operational management thresholds, and therefore aid in the development of the decision-making process among regulators, developers and stakeholders (DFO, 2006). Such landscape scenarios via modelling explore whether recent changes in an ecosystem are within the normal range of variability of these areas.

Models also provide a form directly relevant to the development of indicators and thresholds of concern used in ecosystem management. In many ecosystems where shellfish aquaculture is prominent, it is possible to utilize ecosystem models to;

- assess the potential impact of shellfish on ecosystem state,
- define indicators based on predicted fluxes in order to summarize ecosystem properties (nutrient throughput, recycling and time scales),
- compare ecosystems using the selected set of indicators,
- assess interactions between aquaculture and other human activities in the coastal zone,
- assess ecosystem functioning on the long term and determine if aquaculture ecosystem interactions interfere with other services provided by the ecosystem, and
- define ecological thresholds linked to the density-dependant effects of shellfish aquaculture.

Model-based indicators may be a cost-effective alternative to extensive field studies that may or may not be able to differentiate between anthropogenic impacts and the large variations that occur naturally. A number of countries have well-developed policies and procedures in place that utilize modelling tools for planning and monitoring as well as regulation of impacts from nutrient enhancement, organic waste deposition and the dispersion and deposition of medicines and chemicals (reviewed by Henderson *et al.,* 2001). However, the use of models for the regulation and monitoring of aquaculture has been restricted to finfish applications in a relatively small number of countries and model applications have been limited to site application assessments, the identification of holding capacity and the licensing of medicines (Henderson *et al.,* 2001). With respect to shellfish, the models that are in current use to predict production carrying capacity, food depletion and ecological interactions are only indirectly utilized in regulatory activities. However, predictions from models can be obtained quickly and are contributing to the movement from reactive to proactive management.

The final report of the MARAQUA project recommended greater use of modelling as a means to achieving best practice. MARAQUA suggested that "modelling can play a key role in monitoring the release of nutrients and organics; the dispersion of chemicals to the sea bed; the effects of structures on habitat change; in risk assessment of escaped fish impinging on the environment; and in assisting planners, producers and regulators in understanding the impacts of aquaculture in a way that will enable them to develop environmental management and sustainability strategies." While several of these benefits are not relevant to shellfish culture (fate of chemical additions), ecosystem modelling of shellfish culture is believed to be at a more advanced state than for finfish, particularly with respect to predicting pelagic effects.

4.5 Thresholds

"Threshold" is a general term of value which can be determined by administrative or scientific processes. For example, there are thresholds such as "no change in water colour due to eutrophication". That is a threshold derived from policy implementation of a sense of what is socially acceptable. The scientific expression might be "no more or less than 1 μg l^{-1} of chlorophyll". The threshold in this case is set by a policy statement. In contrast, if the desire is to prevent mortality of clams you might set the threshold for 6 mg l^{-1}. That is a threshold defined by our scientific knowledge of the organisms' response to environmental change. There are other less well-defined thresholds which determine the point at which ecosystems show a sudden regime shift from one state to another. For example, a trophic web based on microalgae is a highly productive system for bivalve culture, however, if that system suddenly shifted to a system based on pico-phytoplankton it may have the same or more primary productivity but much of it would not be available to bivalves. In identifying a threshold it is important to be clear on whether the threshold is one determined by policy decisions or by changes in ecosystems.

It is difficult to set a threshold and sometimes the criterion is simply a "no net loss" or "no change". (Un)fortunately, nature is not static. The environment is always changing. To set an adequate threshold, scientists, managers and all stakeholders must together identify the value of acceptable change from reference conditions. To address these difficulties, ecosystem managers increasingly use a monitoring endpoint, known as thresholds of potential concern (TPC), to decide when management intervention is needed (Biggs and Rogers, 2003). TPCs are a set of operational goals along a continuum of change in selected environmental indicators (Gillson and Duffin, 2007). TPCs are being continually adjusted in response to the emergence of new ecological information or changing management goals. They provide a conceptual tool that enables ecosystem managers to apply variability concepts in their management plans, by distinguishing normal "background" variability from unpredicted change or degradation (Gillson and Duffin, 2007).

The use of thresholds is often based on mean values but it has been shown in many studies that the ecosystem's response to a disturbance is an increase in variability. It is possible to observe no change in the mean values of the indices, although the variability may increase through time, making it impossible to adequately select a threshold. However, setting thresholds based on means are often not enough. It is often the extremes that shift ecological status.

The following is an example of how extreme conditions can have important ecological and aquaculture implications. The cockle (*Cerastoderma edule* L.) is the dominant species at the mouth of the Ulla River, located in the Ría de Arousa of Spain. Normally salinity conditions in the area support a thriving population of cockles (more than 500 T extracted worth approximately 2 million € per year). However, a prohibition of sand extraction from the river bed in recent years, together with tidal currents, dam controlled flow discharges in the river and strong winter winds has created new intertidal sand banks. These sand banks modify the mixing of fresh and sea waters in the area. Occasionally, this new configuration of sand banks leads to a reduction of salinity in cockle beds (below 10 ppm) for period of 24 h or more. That reduction in salinity results in the death of an important part of the cockle stock. So, while on average the conditions in Ulla River mouth would normally favour cockle growth the occasional dip in salinities make the area no longer suitable for cockle rearing.

In the case of large areas of shellfish cultivation it is not always possible to set thresholds as there is considerable spatial variability in the natural spatial distribution of water quality parameters. Consequently when thresholds are set it is important to determine the sampling design criteria that must be used to determine if a threshold has been passed. Some examples of considerations in deriving the design of sampling methodologies include:

- geographic and topographic location (e.g. Rias, Fjords, Wadden Sea),

- the intensity of culture relative to the area and/or volume of the embayment,
- the time (annually) of spawning events or the appearance of algal blooms (e.g. mussel spawning event Spain: March; the Netherlands/Germany: May; unpredictable appearance of algal blooms),
- the rate of depletion of phytoplankton within bays, estuaries or the open ocean (e.g. exchange/mixing of water body is different; influx from tidal backwaters or other productive areas [North Sea, Rias]),
- the rate of deposition of faeces in high energy environments or water bodies with low currents (e.g. Fjords ↔ open ocean)
- the rate of oxygen depletion within the water column (e.g. low mixing of water and high production of organic matter → raft culture)

There is a need to consider how regional and operational differences impact the applicability of indices and thresholds for assessing shellfish aquaculture ecological effects. Any recommended framework of methodologies and approaches for assessing shellfish aquaculture impacts must incorporates sufficient flexibility to be of use over a wide range of culture species, husbandry practices, and environmental settings, and that is applicable to small to large shellfish aquaculture operations (Cranford *et al.*, 2006). Given the highly diverse nature of the shellfish aquaculture industry, it is not sufficient to simply provide a toolbox of potential indicators and thresholds; it is equally important to make recommendations, based on sound science, as to which tools are most appropriate under different conditions.

In some instances it may be possible to manage small scale environmental conditions by managing aquaculture. However, as the scale of the area to be managed increases, so many other users and factors have to be considered that managing aquaculture alone is inadequate for managing environmental quality. In areas that are traditionally used for shellfish culture and which have at the same time a high annual production output could have an impact on the surrounding ecosystem. Under these conditions, the definition of thresholds for this area makes sense in terms of ecosystem protection or risk management.

There are a large number of different husbandry approaches to shellfish culture. The type of culture will differ in aspects of their interactions with the environment. For example, intertidal culture constantly modifies the natural community on the beach, while longline culture seldom directly affects beach communities. It is therefore often useful to start the search for threshold parameters or indices by considering the type of shellfish culture to be undertaken. Other types of culture techniques include raft, rack (poche), and pole (bouchot) culture.

A possible solution for managing shellfish aquaculture may be the use of qualitative categories for potential environmental change based on the principle that increased environmental risk requires an increase in monitoring effort. The degree of risk may be linked to a list of pre-identified indicators, with the different classes of indicators triggered based on:

- the nature of the operation (e.g. species, culture method and stocking density per area or volume);
- the perceived environmental risk (e.g. EIA and model-based predictions);
- the ongoing measurement of environmental indicators towards verification of operational thresholds; and

- other environmental sensitivity indices (e.g. habitat sensitivity designations).

Instead of partitioning the range of variation of an indicator into 2 classes (acceptable = under threshold and unacceptable = over threshold), a few more classes / categories may be more pertinent in specific cases (like in the case of European microbiological zonation based on different concentrations of *E. coli*). Such a system is currently employed in parts of eastern Canada to manage benthic effects from aquaculture. This *responsive management framework* is designed to avoid harmful alterations, disruptions and destruction of fish habitat and relies on a tiered approach to site management. A series of *operational thresholds* are defined by total free sulphide (S) and redox potential (Eh) in sediment collected at aquaculture sites. Progressively more rigorous monitoring and management requirements are automatically implemented in response to degrading site classification, based on pre-defined benchmarks. Monitoring and site management responses are used to delineate the temporal and spatial extent of the effect and promote oxic benthic sediment conditions.

The inability to adequately define quantitative operational thresholds for some highly relevant indicators of ecosystem performance/status (particularly those describing the structure and dynamics of the water column), owing to present gaps in our knowledge of ecosystems, should not preclude their potential use. The monitoring of relevant indicators is desirable under conditions where environmental impact assessments and ongoing monitoring data indicate a relatively high risk of bay-scale impacts. Of particular concern are potential impacts on suspended particle concentrations and distribution and resulting alterations in pelagic microflora and fauna communities and the pelagic food web. Monitoring of a suite of ecosystem traits that are thought to affect community structure and functional performance (i.e. contextual indicators), is warranted when and where significant water column interactions with the farm (e.g. significant particle depletion) is predicted (see Section 4.3). Surveillance of pelagic indicators would compliment benthic operational monitoring and would support the basic monitoring principle of delineating cause-effect relationships.

4.6 Conclusions and Recommendations:

Shellfish aquaculture operates in a highly complex legal and policy framework in Europe. However, this should not be viewed as a constraint, but rather an opportunity for supporting shellfish aquaculture best practices. A case in point is the establishment and extension of several EU-wide monitoring programmes that could endorse a set of multi-scale indicators relevant to shellfish aquaculture. Preliminary recommendations for this ToR are as follows:

1) There is a need to consider how regional and operational differences impact the applicability of indices and thresholds for assessing shellfish aquaculture ecological effects. Any recommended framework of methodologies and approaches for assessing shellfish aquaculture impacts must incorporates sufficient flexibility to be of use over a wide range of culture species, husbandry practices, and environmental settings, and that is applicable to small to large shellfish aquaculture operations. A solution for managing shellfish aquaculture may be development of a tiered approach to managing potential and observed environmental change based on the principle that increased environmental risk requires an increase in monitoring effort.

2) There has been a considerable effort by the WGMASC to compile a list of indicators relevant to managing shellfish aquaculture operations. As a next step, these should be integrated with the social and institutional indicators of other ICES expert groups, namely with those developed (or are in the stage of being developed) by the WGICZM, and streamlined with existing programmes on the international level. The WGMASC recommends to link stronger with the WGICZM and to include socio-economic perspectives in the analysis of shellfish aquaculture. An integration of such EG activities may be best accomplished within a cross-cutting ICES Science Program that includes members from multiple expert groups.

3) Additional expertise is needed within the WGMASC to review the relevant legislative and policy framework in the EU legislation and policies in North America in which shellfish cultivation and the monitoring of key indicators may take place. The appointment of an expert by the chair is recommended for participation in the next WGMASC annual meeting.

4) An operational threshold used within an ecosystem-based management framework of shellfish culture should be based on a natural scientific background while at the same time the societal values of ICES member countries should be incorporated when deciding how important a change would be before it is considered unacceptable. The latter acts as the key denominator for the definition and local acceptance of thresholds for the respective indicator, since they reflect the basic overarching logic of local/regional decision-making and their respective societal values. One of the important functions of identifying indicators and associated management thresholds is that they can act as a bridge between science and policy.

5) We recommend the further application of models to assist in the development of indicators and thresholds of concern by predicting changes in ecosystem properties, fluxes and time scales under different environmental settings.

6) Future work on this ToR should include;

6.1) prioritization of identified indicators based on selection criteria described in this report. A small set of well-chosen indicators tends to be the favourite choice of most indicators users, including the stakeholders for aquaculture,

6.2) a review and recommendations on a flexible and pragmatic, but scientifically-defensible, monitoring approach that is relevant to a highly diverse industry,

6.3) identification of a *series* of operational thresholds for each recommended indicator such that increasingly degraded site classifications can be linked to progressively more assertive management actions, and

6.4) identification of decision-support tools.

4.7 References

Biesen, G. V., and Parrish, C. C. 2005. Long-chain monounsaturated fatty acids as biomarkers for the dispersal of organic waste from a fish enclosure. Mar. Env. Res., 60: 375–388

Biggs, H.C., and Rogers, K. H. 2003. An adaptive system to link science, monitoring and management in practice, pp. 59–80. *In*: du Toit, J.T., K.H. Rogers and H.C. Biggs (Eds.): The

Kruger experience: ecology and management of savannah heterogeneity. Washington, DC, Island Press.

Bricker, S. B., Clement, C. G., Pirhalla, D. E., Orlando, S. P., and Farrow, D. R. G. 1999. National Estuarine Eutrophication Assessment: Effects of Nutrient Enrichment in the Nations Estuaries. National Oceanic and Atmospheric Administration, National Ocean Service, Special Projects Office and the National Centers for Coastal Ocean Science. Silver Spring, Maryland. 71p.

Carpenter, S. R., and Brock, W. A. 2006. Rising variance: a leading indicator of ecological transition. Ecology Letters 9 (3): 311–318.

Carpenter, S. R., Brock, W. A., Cole, J. J., Kitchell, J. F., Pace, M. L. 2008. Leading indicators of trophic cascades. Ecology Letters, 11 (2): 128–138.

Chamberlain, J., Weise, A.M., Dowd, M., and Grant, J. 2006. Modeling approaches to assess the potential effects of shellfish aquaculture on the marine environment. DFO Can. Sci. Advis. Sec. Res. Doc. - 2006/032. http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2006/RES2006_032_e.pdf

Cranford, P.J., Anderson, R., Archambault, P., Balch, T., Bates, S.S., Bugden, G., Callier, M.D., Carver, C., Comeau, L., Hargrave, B., Harrison, W.G., Horne, E., Kepkay, P.E., Li, W.K.W., Mallet, A., Ouellette, M. and Strain, P. 2006. Indicators and Thresholds for Use in Assessing Shellfish Aquaculture Impacts on Fish Habitat, CSAS-DFO, Research documemt 2006/034, 116 p. http://www.dfo-mpo.gc.ca/csas/Csas/DocREC/2006/RES2006_034_e.pdf

Cranford, P.J., Strain, P.M., Dowd, M., Hargrave, B.T., Grant, J. and Archambault, M-C. 2007. Influence of mussel aquaculture on nitrogen dynamics in a nutrient enriched coastal embayment. Mar. Ecol. Prog. Ser., 347: 61–78.

Cromey, C. J., Nickell, T. D. *et al*., 2002. DEPOMOD-modelling the deposition and biological effects of waste solids from marine cage farms. Aquaculture, 214(1–4): 211–239.

Dale, V. H., and Beyeler, S. C. 2001. "Challenges in the development and use of ecological indicators." Ecological Indicators, 1(1): 3–10.

Garcia, S. M., and Staples, D. J. 2000. "The FAO definition of sustainable development and the Code of Conduct for Responsible Fisheries : an analysis of the related principles, criteria and indicators. Sustainability Indicators in Marine Capture Fisheries." Mar. Freshwater Res., 51 (5): 535–541.

Gillson, L., and Duffin, K.I. 2007. Thresholds of potential concern as benchmarks in the management of African savannahs. Philosophical Transactions of the Royal Society, 362:309–319.

DFO, 2006. Assessing habitat risks associated with bivalve aquaculture in the marine environment. DFO Can. Sci. Advis. Sec. Sci. Advis. Rept. 2006/005. http://www.dfo-mpo.gc.ca/csas/Csas/status/2006/SAR-AS2006_005_E.pdf

European Commission, 1985. Directive on the Assessment of Effects of Certain Public and Private Projects on the Environment (Environmental Impact Assessment), Council Directive 85/337/EEC, 27 June 1985. Official Journal NO. L 175 , 05/07/1985 P. 0040 – 0048.

European Commission, 1996. Council Directive Concerning Integrated Pollution Prevention and Control (the IPPC Directive), Council Directive 96/61/EC, Official Journal L 257, 10.10.1996, p 26 and amendments.

European Commission, 1997. Council Directive 97/11/EC of 3 March 1997 amending Directive 85/337/EEC on the Assessment of Effects of Certain Public and Private Projects on the Environment (Environmental Impact Assessment). Official Journal No. L 073, 14/03/1997 P. 0005.

European Commission, 1999. Towards a European Integrated Coastal Zone Management (ICZM) Strategy: General Principles and Policy Options. Directorates General:

Environment, Nuclear Safety and Civil Protection; Fisheries: Regional Policies and Cohesion. European Commission, Brussels.

European Commission, 2000. The EU Water Framework Directive – integrated river basin management for Europe. Directive 2000/60/EC, Official Journal (OJ L 327), 22 December 2000.

European Commission, 2000. The Lisbon European Council – An Agenda of economic and social renewal for Europe. Contribution of the European Commission to the special European council in Lisbon, 23–24 March 2000 DOC/00/7 Brussels, 28 February 2000

European Council, 2000. Presidency conclusions. Lisbon European Council. Lisbon European Council, 23 and 24 March 2000.

European Commission, 2001a. The assessment of the effects of certain plans and programmes on the environment, Directive 2001/42/EC, Official Journal L 197, 21/07/2001 P. 0030 – 0037. 27 June 2000.

European Commission, 2001b. European Governance, A White Paper. COM (2001) 428 final.

European Commission, 2002a. Recommendation of the European Parliament and of the Council of 30 May 2002 concerning the implementation of Integrated Coastal Zone Management (ICZM) 2002/413/EC. OJ 6.6.2002, L148/24.

European Commission, 2002b. Decision No 1600/2002/EC of the European Parliament and of the Council of 22 July 2002 laying down the Sixth Community Environment Action Programme, published in OJ L 242 of 10/9/2002.

European Commission, 2004a. Communication from the Commission to the European Parliament and the Council. Global Monitoring for Environment and Security (GMES): Establishing a GMES capacity by 2008 – Action Plan (2004–2008). Brussels, 3.2.2004, COM (2004) 65 final.

European Commission, 2004b. Proposal for a Directive of the European Parliament and of the Council establishing an infrastructure for spatial information in the Community (INSPIRE), SEC(2004) 980. COM(2004)516 final.

European Commission, 2005a. Directive of the European Parliament and of the Council establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Directive), COM(2005)505 final, 24 October 2005.

European Commission, 2005b. Spatial Data Infrastructures in Europe: State of play Spring 2005. Summary Report of Activity 5 of a study commissioned by the EC in the framework of the INSPIRE initiative.

European Commission, 2005c. A new start for the Lisbon Strategy– delivering stronger, lasting growth and more and better jobs. COM (2005) 24 of 2.2.2005

European Commission, 2006a. Evaluation of Integrated Coastal Zone Management (ICZM) in Europe. Final Report. 255 pages. http://ec.europa.eu/environment/iczm/ and http://ec.europa.eu/environment/iczm/pdf/evaluation_iczm_report.pdf

European Commission, 2006b. Community strategic guidelines on cohesion (2006/702/EC). 6 October 2006.

European Commission, 2006c. Green Paper, Towards a Future Maritime Policy for the Union: A European Vision for the Oceans and Seas. COM(2006)275 final.

Garcia, S. M., and Staples, D. J. 2000. "The FAO definition of sustainable development and the Code of Conduct for Responsible Fisheries: an analysis of the related principles, criteria and indicators. Sustainability Indicators in Marine Capture Fisheries." Mar. Freshwater Res., 51 (5): 535–541.G

Gibbs, M.T. 2007. Sustainability performance indicators for suspended bivalve aquaculture activities. Ecol. Indicators, 7: 94–107.

Gilbert, A.J., and Feenstra, J.F., 1993. A sustainability indicator for the Dutch environmental policy theme 'Diffusion': cadmium accumulation in soil. Ecol. Economics, 9: 253–265.

Grant, J., Hatcher, A. *et al*., 1995. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. Estuaries, 18(1A): 124–144.

Henderson, A.R., Gamito, S., Karakassis, I., Maroni, K., Pedersen, P.B., and Smaal, A.C. 2001. Use of hydrodynamic and benthic models for managing environmental impacts. Journal of Applied Ichthyology, 17 (4): 163–172

Héral, M., Bacher, C., *et al*., 1989. La capacité biotique des bassins conchylicoles. L'Homme et les ressources halieutiques. Essai sur l'usage d'une ressource renouvelable. J. P. Troadec. Brest, IFREMER: 224–259.

Janssen, M.A., and Ostrom, E. 2006. Governing Social-Ecological Systems. *In*: Handbook of Computational Economics, Vol. 2: 1465–1509 pp.

Kristensen, E. 2000. Organic matter diagenesis at the oxic/anoxic interface in coastal marine sediments, with emphasis on the role of burrowing animals. Hydrobiologia, 426(1): 1–24.

Kurtz, J. C., Jackson, L. E. *et al*., 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecol. Indicators, 1: 49–60.

Liverman D.M., Hanson, M.E., Brown, B.J., and Merideth, R.W. 1988. Global sustainability: Towards measurements. Environmental Management, 12(2):133–143.

Nicholson, M., and Fryer, R. 2002. Developing effective environmental indicators–does a new dog need old tricks? Mar. Poll. Bull., 45(1): 53–61.

OECD.2000. Framework to measure sustainable development. Paris, France, OECD.

Olsen, S. B. 2003. Frameworks and indicators for assessing progress in integrated coastal management initiatives. Ocean & Coastal Management, 46(3–4): 347–361.

Pearson, T. H., and Rosenberg, R. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanogr. Mar. Biol. Ann., Rev. 16: 229–311.

Rice, J. 2003. Environmental health indicators. Ocean and Coastal Management, 46: 235–259.

Rice, J. 2005. Guidance on the application of the ecosystem approach to management of human activities in the European marine environment. ICES Coop. Res. Rep., 273, 22 p.

Rochet, M. J., and Trenkel, V. M. 2003. Which community indicators can measure the impact of fishing? A review and proposals. Can. J. Fish.Aquat. Sci., 86–99.

Rudd, M. A. 2004. An institutional framework for designing and monitoring ecosystem-based fisheries management policy experiments. Ecological Economics, 48: 109–124.

Segnestam, L. 2002. Indicators of environment and sustainable development, The World Bank Environment Department, 61 p.

Spangenberg, J. H. 2002. Environmental space and the prism of sustainability: frameworks for indicators measuring sustainable development. Ecol. Indicators, 2(3): 295–309.

Zurek, M.B., and Henrichs, T. 2007. Linking scenarios across geographical scales in international environmental assessments. Technological Forecasting & Social Change, Vol. 74 (8): 1282–1295 pp.

5 Review knowledge and report on the significance of bivalve aquaculture transfers between sites (local, national, international) to wild and cultured bivalve stocks (ToR c)

5.1 Background

Movement of shellfish around the world is an activity that has a long history (Wolff and Reise, 2002). The objective is always economic, to develop a sustainable food supply, to replenish a depleted stock, or to start a new culture. ICES Member Countries import live organisms from 32 countries and molluscs are among the most important taxa transported (WGITMO, 2006). The transport of different shellfish species including life stages from hatcheries, from field sites to new culture or wild fishery sites, often crossing international boundaries, has potential implications – through the introduction of shellfish and their associated organisms. These can include non-indigenous species, potentially toxic algae, viruses, bacteria, disease agents or parasites. Potential implications can be interactions with wild and cultured stocks (impact on recruitment, loss of cultivated organisms, sterilization, reduced fitness and fecundity, less meat content, competition, risk of predation, or change in genetic composition, diversity and polymorphism, and physiological and morphological traits; Ambariyanto and Seed, 1991, Calvo-Ugarteburu and McQuaid, 1998, Camacho *et al.*, 1997, Desclaux *et al.*, 2004, Dethlefsen 1975, Taskinen 1998, Tiews, 1988, Wegeberg and Jensen, 1999, Wegeberg and Jensen, 2003).

Presently, a number of ICES working groups are concerned with the topic of transferring marine organisms. The Study Group on Ballast and Other Ship Vectors (SGBOSV) work on specifically identified vectors of ballast water and hull fouling. The Working Group on Introductions and Transfers of Marine Organisms (WGITMO) documents the spread of intentionally imported and/or invasive species introductions via the use of National Reports from many ICES countries. WGITMO's work focuses on the aquaculture vector and what happens when an invasive species is found in a water body (no matter what vector is involved) – origin and status of the invasion, potential impacts, options for mitigation and/or eradication, and sharing information with other countries. The WGITMO deals mainly with intentional introductions for e.g. aquaculture purposes, and works to reduce unintentional introductions of exotic and deleterious species such as parasites and disease agents through a risk assessment process and quarantine recommendations. The Working Group on Environmental Interactions of Mariculture (WGEIM) is examining the potential importance of bivalve culture in the promotion and transfer of exotic species (i.e. alien or introduced) and the resulting implications for bivalve culture and the environment. The WGEIM is also examining management and mitigation approaches for invasive and nuisance species that have been transferred to aquaculture sites.

The WGEIM (2006) report recommended to the Mariculture Committee that key representatives from ICES Working Groups dealing with aquatic exotic species, including the WGMASC, should meet to, among other tasks, identify information gaps and recommend specific research goals. The MASC working group concurred with this recommendation and recommended in 2007 to the MCC that the WGMASC undertake a new ToR on this high priority topic, beginning in 2008, to avoid overlap between Terms of Reference. The relevant reports of WGEIM and WGITMO are summarised below.

5.2 Related reports of WGITMO and WGEIM

5.2.1 2007 of the WGITMO[1]

Some sections within this report can be referenced within ToR c) of the WGMASC, such as the ToR f) "Status of development of ICES Alien Species Alert reports" including the evaluation of impacts and to increase public awareness. The aim is to finalize the ToR f) report at next years meeting. In subsequent years additional taxonomic groups may be identified those more likely to be introduced deliberately as food, or accidentally by other vectors.

The report focuses on various species, especially on the Pacific oyster *Crassostrea gigas* (including the biology, the introduction for aquaculture purposes, the consequences of Pacific oyster introduction, mitigations and restorations, and finally a prospective). Further the question of the introduction of *C. ariakensis* to some areas of the US, primarily as nonsterile triploids, can be considered (including an environmental impact statement with alternatives, scientific contributions in support of the EIS, and a review concerning the utility of ICES Code of Practice guidelines in the current process). This deliberate introduction offered an opportunity to evaluate: how well the Code of Practice (ICES) is being followed; the Code's strengths and weaknesses, and what can be said about the risks involved in the process that the US adopted.

5.2.2 2005 report of the WGEIM

The potential effect of transfer of non-indigenous species on wild and cultured stocks of bivalve was **not** discussed in the terms of references. However, in Annex 3[2] the international trade rules from the World Trade Organization (WTO), by the Office International des Epizootic (OIE) and the Code of Practice for the Introduction and Transfer of Marine Organisms (ICES, 2003) are mentioned (see description field below). This text can be adapted to shellfish aquaculture issues also.

Use of Risk Analysis Internationally

In response to concerns about disease transfer and control, WTO accepts the risk analysis protocols developed by the Office International des Epizootic (OIE) as the basis for justifying trade restricting regulatory actions including restriction on movement of commercial and non-commercial aquatic animals. The intent of developing the OIE protocols was to provide guidelines and principles for conducting transparent, objective and defensible risk analyses for international trade. ICES has embraced this approach in their latest (2003) Code of Practice for the Introduction and Transfer of Marine Organisms (hereafter referred to as the ICES Code). One part of the ICES Code is specifically designed to address the "ecological and environmental impacts of introduced and transferred species that may escape the confines of cultivation and become established in the receiving environment". Unfortunately, examples of the application of risk analysis to the development of regulations have not been generally published in the primary scientific literature.

Finally, ToR g) of the recommendations "investigate the hazards associated with mariculture structures in terms of habitat change/modification and assess their

1 Other reports from previous meetings were not available via the ICES homepage.

2 "State of knowledge" of the potential impacts of escaped aquaculture marine (non-salmonid) finfish species on local native wild stocks and complete the risk analyses of escapes of non-salmonid farmed fish - a Risk Analysis Template.

potential for accommodating invasive/nuisance species in a system – proposed in consultation with WGITMO should be investigated" will be of use for shellfish aquaculture issues.

5.2.3 2006 report of the WGEIM

The potential effect of transfer of non-indigenous species on wild and cultured stocks of bivalve was discussed in the terms of references f (former ToR g). Their aim was to "examine the **potential importance** of bivalve culture in the **promotion** and **transfer** of exotic aquatic species as well as the importance of these exotic species to **bivalve culture and the environment**". The focus was on exotic species with an emphasis on those that become invasive and nuisance. Management implications and mitigation strategies are also addressed. The information presented is largely based on oyster-oriented literature but has been expanded where possible to include other taxa. The report covers many aspects that are important to shellfish culture such as the effects of exotic species – including exotic macrospecies – animals and algae –, exotic phytoplankton and disease species, on fouling, competition, predation, algae smothering shellfish, introduction of phytoplankton that causes harmful algal blooms, mass mortality due to disease transfer (viruses, bacteria, protozoans, higher invertebrates) on cultured bivalves.

Here, it was recommended by the WGEIM to organize a meeting with the appropriate members of other working groups (WGMASC, WGITMO, SGBOSV) to discuss these topics and to prepare a joint document.

5.2.4 2007 report of the WGEIM

The potential effect of transfer of non-indigenous species on wild and cultured stocks of bivalves was not discussed. However, in ToR d) (Further investigate fouling hazards associated with the physical structures used in Mariculture and assess their potential for the introduction of invasive/nuisance species into the local environment.) the concept of Integrated Pest Management is mentioned to decrease the impact of non-indigenous (and pest) species.

5.3 Focus of WGMASC

Tor C will focus on the significance of bivalve aquaculture transfers between sites (local, regional, national, and international) to wild and cultured bivalve stocks. The transported shellfish are the vector for any associated organisms, while the target species (the wild and cultured shellfish) are monitored to assess any impact prior to and post deposit. Information is being collected on current *guidelines in place and records kept* in ICES countries related to the transfer of cultured species to assess those impacts. Effects of shellfish relocations (including epifauna, epiflora, associated organisms, diseases and parasites): on the *geographic distribution of marine organisms; indigenous shellfish stock traits* (impact on recruitment, loss of cultivated organisms, sterilization, reduced fitness and fecundity, less meat content, competition, risk of predation, or change in genetic composition, diversity and polymorphism, and physiological and morphological traits), and the *potential implications* for regional shellfish culture operations are considered. In addition, suggestions for *scientific tools to support policy decisions* and *recommendations to farmers and policy makers* on cultured shellfish transfer issues will be given. Since many of the topics mentioned above are already covered in part by the 2006 report of WGEIM, the work of WGMASC can be seen as an addition to this report.

5.4 Work plan

In this first year the role of WGMASC was defined; following the screening of the SGBOSV, WGIMTO and WGEIM reports and considering risks not covered by those terms of reference. In addition, current guidelines and records are to be reviewed together with a summery of shellfish movements not covered by those reports. In year 2 the collection and collation of data is to continue, the ToR to be completed in year 3 with a final report including recommendations on scientific tools for decision support and on shellfish transfers in general

5.5 Guidelines

5.5.1 Introduction

Aquaculture must compete for and share space with other interests such as fisheries (the public right to fish); anchorages, effluent discharges, sites of scientific interest, tourism etc. Legislation and industry codes of practice exist worldwide to control environmental impacts and diseases associated with transfers of molluscan shellfish species, both cultured and wild. These include: the ICES code of practice; OIE guidelines; natural heritage organisations (e.g. English Heritage & Scottish Natural Heritage in Britain) concerning conservation and sustainability of resources, and EU council directives related to both shellfish and human health, e.g. Directive 2006/113/EC of the European parliament and of the council of 12 December 2006, on the quality required of shellfish waters. In addition, in the absence of statute or CoPs, negotiation between industry and authority is often used at the local level to help protect the environment. A review of these guidelines is intended to show where and how controls are implemented and how these may be integrated and developed to minimise the risk of environmental influences including disease.

The United Nations Convention on Law of the Sea (UNCLOS) is an international agreement which defines the rights and responsibilities of nations in their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. To date 155 countries and the European Community have joined in the Convention. A management role is played by organizations such as the International Maritime Organization, the International Whaling Commission, and the International Seabed Authority

The international law of the sea includes the exploration and exploitation of the exclusive economic zones (EEZ) of all countries in which these countries are able to exploit (e.g. harvest) their resources (including aquaculture). The exploration and exploitation of the exclusive economic zones (EEZs) has become of major importance for maritime countries. The knowledge of sub-bottom potential requires innovative underwater tools for optimization of research and exploitation. Technologies used are, in the main, drawn from different fields such as: imagery, bathymetry, marine seismic, current profiling, underwater positioning, magnetometry and subbottom analysis. EEZ exploitation requires the analysis of areas for industrial applications as well as scientific analysis. Seafloor analysis and mapping are of prime importance for fluid migration and margin structural analysis. One of the major steps in surveying is the use of bathymetry and imagery analysis, which allows geologists to analyze the seabed structure. Bathymetric surveying is of great importance too, for cable and pipe laying (Denis, Jean-Francois Sea Technology, February 2001).

Fish farming has an impact on the environment and that impact can be minimised by statute, consultation and good work practice. Most EU countries employ a complex aquaculture planning consultation process to minimize the environmental impact of developments and ensure the deposit and cultivation of aquaculture animals does not conflict with rights of others, e.g. an application for a farm lease in Scotland involves consultation with: Fisheries Research Services on the feasibility, environmental and disease implications of proposals; The Scottish Environmental protection Agency (SEPA) on discharge consents; Wild fishery interests by the Fisheries protection Agency and Fishermen's associations; potential conflicts of interest by local Harbour Authority, Scottish Pelagic Fishermen's Association, Scottish Anglers National Associations District Salmon Fisheries Boards and the Ministry of Defense; Scottish Natural Heritage who consider the ecosystem and aesthetic impact of an application; Health and Safety executive whose aim is to protect people against risks to health or safety arising out of work activities, and local press on public awareness, where seeking valid objections to a development

If a lease is granted, the weight of statute helps set standards, e.g. Under the Environmental Impact Assessment (Fish Farming in Marine Waters) Regulations 1999. An application is likely to involve an environmental statement and an Environmental impact assessment (EIA). In addition industry codes of practice are designed to encourage sustainability with minimum impact, e.g. the Association of Scottish Shellfish Growers Code of Best Practice for shellfish aquaculture (http://www.assg.co.uk/).

The following Controls and Codes of Good Practice are reviewed below:

- European legislation
- ICES Code of Practice
- National legislation
- Industry Codes of Practice
- OIE guidelines
- Natural Heritage Organisations
- English Heritage, Scottish National Heritage, Countryside Council for Wales
- Negotiation at local level

5.5.2 European legislation

With the adoption of the single European market in 1992, in order to promote trade among Member States, including that in live fish and shellfish, an EU Fish Health Regime was established to limit the introduction and spread of the most serious diseases across Europe. This was based on Council Directives 91/67 EEC, 95/70/EC and subsequent Directives and Decisions, subsequently implemented by current fish health regulations. They list controls that may be applied by member countries for certain diseases of shellfish, and established the concept of Approved Zones and Farms for serious (list II) diseases (*Bonami*a and *Marteilia*), and introduced controls on movements to such Approved Zones and Farms, which were restricted to shellfish from sources of equivalent or higher health status. With EU agreement national programmes could then be established to prevent, control, contain or eradicate the disease. This legislation is to be replaced by directive 2006/88/EC, in the latter half of 2008.

5.5.2.1 Council Directive 91/67/EC

Movements of shellfish within the EU: The EU fish health regime requires that movements of molluscan shellfish susceptible to *Marteilia* and *Bonamia* are only made between zones or farms of equivalent health status and that movements of non-susceptible molluscs do not carry the risk of transfer of these pathogens or hitch hiker species to approved zones or farms.

Lists of specific shellfish diseases and susceptible species are listed in Annex A of 91/67/EC and Annex D of 95/70/EC.

Consignments of susceptible shellfish species, for relaying or placing in depuration facilities prior to consumption into approved zones, must be accompanied by movement documents confirming the health status of the consignment. Each document must be signed by the Official Service in the region of origin and be drawn up at the place of origin within 48 hours prior to loading, in the language of place of destination, valid for 10 days of travel. All other species of molluscan shellfish must originate from *Marteilia* and Bonamia Approved Zones or Farms, or from other farms that do not hold species susceptible to *Marteilia* and *Bonamia* and which are not connected to any other water (using non susceptible species certificate as per 2003/390/EC, Annex 1, to be signed 24 hours prior to loading).

Inspectors must inspect and sign consignments prior to export, ensuring no clinical disease or the presence of hitch hiker species. If hitch hikers cannot be removed details must be provided on the certificate to prevent their introduction.

5.5.2.2 EC Directive 2006/88/EC

This directive on the animal health requirements for aquaculture animals comes into force in August 2008, when it will replace 91/67/EEC. Amongst the significant changes to previous requirements, the new legislation will adopt the following approach:

- a risk-based approach, notably for official surveillance for disease;
- requirement for "Aquaculture Production Businesses" to comply with conditions of authorisation
- controls on movements of potential vector and non-susceptible species;
- a structure for declaring the health status of Member States and compartments, in addition to zones;
- the facility for Member States to self-declare disease freedom for zones and compartments

Specifically, APB's will be required to:

- Keep a record of all movements of aquaculture animals and products, including dead fish
- Keep a record of mortalities occurring on the farm
- Participate in a risk based surveillance scheme and keep records of the results of any such scheme
- Implement and maintain good bio-security practices (referred to in the Directive as good hygiene practice).

Disease control: The Directive requires that competent authorities have measures in place that will prevent the introduction and control the spread of certain listed diseases. These diseases have been divided into two categories; exotic and Non-exotic. For bivalve molluscs the Exotic diseases are listed as: infection with *Bonamia exitiosa*, infection with *Perkinsus marinus* and infection with *Microcytos mackini*. The

Non-Exotic diseases are listed as: infection with *Bonamia ostreae* and infection with *Marteilia refringens*.

Under 2006/88EC, under the draft certificate, all susceptible and vector species must be accompanied by a health certificate stating that each consignment be inspected on the day of loading. There is facility for the quarantine, controlling the movement of potential vector species, where these are considered to pose a risk to the health status of member nations.

5.5.2.3 The Water Framework Directive WFD (2000/60/EC)

The water Framework Directive (WFD) requires member states of the EU to characterise the pressures on river basin water bodies, by identifying the impact of ecological and chemical parameters on these aquatic ecosystems. The overall aim is to further improve European waters to meet the environmental objectives of the Directive. Specifically, the WFD requires that surface waters should meet "good ecological and chemical status" by 2015, ensuring in the meantime that no deterioration takes place. The Directive incorporates both chemical and environmental standards, which means that any activities that lead to biological changes, such as the introduction of alien species, must be taken into account during the risk assessment undertaken during the characterisation process.

Risk assessments for individual water bodies will need to take into account the existence, or risk of introduction of alien shellfish species that have the potential to affect the environment. Among the species of interest in Europe that have been associated with aquaculture are: the slipper limpet *Crepidula fornicata*, which has been shown to be a hitch-hiker species carried with introductions of seed mussels; the Manila clam *Tapes philippinarum* and the Pacific oyster *Crassostrea gigas*, both species introduced to replace failing supplies of native species of shellfish. When assessing the impact of the introduction of these and similar species into new waters, the requirements of the Directive need to be taken into account in order to allow the establishment of an environmentally sound aquaculture industry.

5.5.2.4 Hygiene controls on movements of live bivalve molluscs

The European legislation on shellfish hygiene controls are summarised in Directives 852/2004EC and 853/2004EC. These require that transfers of shellfish between areas do not compromise the microbiological quality of either the source or destination. It will be necessary for other ICES member nation representatives to comment on their own countries policies as these views are not available at the present time.

5.5.3 ICES Code of Practice on the Introductions and Transfers of Marine Organisms

This document offers advice and best practice guidance on reducing the risk arising from the introduction of non-indigenous marine species, and includes sections discussing policies for on-going introductions established as part of commercial practice. This guidance sets out a framework for evaluating the risks from such introductions, together with specific procedures for minimising these risks. In doing this, the document repeats some of the requirements covered in the EU legislation and the OIE Aquatic Animal Health Code, as well as describing more detailed methods of inspection of consignments.

5.5.4 National legislation

5.5.4.1 Policy for bivalve transfers in the Netherlands

1) Transfer bivalves into the Wadden Sea is not permitted, except for mussels from the Danish or German parts of the Wadden Sea.

2) To minimize the risks in the Eastern Scheldt, the following precautions are taken:

- Molluscs from risk areas inside the boreal area (from the English channel to the south of Norway and Sweden) may only be transported to the Eastern Scheldt, under licence. Mussel spat from the Dutch part of the Wadden Sea can be transferred to the Eastern Scheldt without permission.
- It's not permitted to transfer molluscs from outside the boreal area into the Eastern Scheldt.
- Processing water and tarra from outside the boreal area must be depurated before discharging it.

A new line of policy concerning the displacement of shellfish came into effect in 1997. Since then the transfer of mussels from the Irish and Celtic Sea into the Oosterschelde has not been permitted. Also the process effluent water and the tare from the consumption mussels originating outside the boreal waters needed to be purified before being discharged into the Oosterschelde (Snijdelaar *et al.,* 2004). In 2003, the Raad van State (Highest Court in the Netherlands) withdrew the ban for import on mussels from the Irish and Celtic Sea. It was brought forward that the ban was conflicting with the EC guidelines for freedom of trade. Also it was substantiated that the precaution principle was formulated as being too general (Snijdelaar *et al.,* 2004). From that period, the Dutch Ministry of Agriculture, Nature and Food Quality, issued permits for the displacement of mussels from the Irish and Celtic Sea into the Oosterschelde. However, the applicant had to prove that mussels originated from a particular production area in the Irish Sea, or have been in that production area for at least one year. In March 2006, the Raad van State decided that the existing permits were not valid. The Oosterschelde is part of the Natura 2000 network based on both the Bird (79/409/EEC) and the Habitat (92/43/EEC) directives. Any plan or project in the area likely to have a significant effect thereon shall be subject to an appropriate assessment of its implications for the site in view of the site's conservation objectives.

In the Netherlands, the production of mussels in the Wadden Sea and the Oosterschelde fluctuates due to varying recruitment and survival rates. Production does not meet the demand for mussels. To meet this demand, seed mussels and adult mussels are imported from other Euopean countries. Wijsman and Smaal (2006) and Wijsman *et al.* (2007a, b) reviewed the risks of transport of mussels from Ireland, the UK, Sweden and Norway to the Dutch production areas. Based on the results of the study, a permit was given to the corporation of shellfish importers to import mussels and oysters from 12 production areas in Ireland and the UK into the Oosterschelde. The imports of consumption mussels from these areas are monitored for the presence of exotic species by means of regular sampling upon arrival in Yerseke. Similar studies have been conducted by Wijsman *et al*. (2007a,b) on the risks in transporting mussels from Norway and Sweden to the Dutch Wadden Sea. At this time the corporation of shellfish importers are applying for a permit for import of mussels and oysters from Norway and Sweden to the Dutch Wadden Sea.

5.5.4.2 Belgian policy

The user conditions as decided by the government of the four bivalve areas in the Belgian North Sea only permit the use of naturally settling spat, obtained by suspended cultivation methods. There are no guidelines for transfers between these areas. The concession owners have to report every notification of non-indigenous species, parasites or diseases to the Management Unit of the North Sea Mathematical Models. A small amount of oyster (both *C. gigas* and *O. edulis*) spat is imported every year for grow out in the Spuikom in Ostend. These oysters are subjected to a veterinary control (Belgian law MB 97/16166).

A review of applicable legislation from other ICES countries will be included in later years.

5.5.5 Discussion

There has been a move towards a more targeted, risk-based, assessment of movements of bivalve molluscs that take place for commercial purposes. There is an understanding from legislators that such movements pose a potential for spread of serious disease, but potential for environmental impacts other than disease is not addressed within the existing animal health legislation. This means that there may be occasions when implementation of the animal health legislation at a European level comes into conflict with ecological legislation at national level.

5.6 Records

5.6.1 Current legislation

Record keeping requirements for shellfish businesses that exist under existing legislation are discussed below. This discussion considers current requirements under European legislation and as with the guidelines on movements, it will be necessary for delegates from other ICES nations to comment on their own countries approach.

5.6.1.1 Record keeping requirements under existing fish and shellfish health legislation

Article 3 of 95/70/EC states that Member States shall ensure that all farms rearing bivalve molluscs:

1) are registered by the official service; this registration must be kept constantly up to date; and

2) keep a record of:

   2.1) live bivalve molluscs entering the farm, containing all information Relating to their delivery, their number or weight, their size and their origin;

   2.2) bivalve molluscs leaving the farm for re-immersion, containing all information relating to their dispatch, their number or weight, their size and destination; and

   2.3) observed abnormal mortality.

This record, which shall be open to scrutiny by the official service at all times, on demand, shall be updated regularly and kept for four years.

Movements of shellfish from outside the EU are required to be accompanied by a suitable animal health certificate, signed by the competent authority

5.6.1.2 Disease records

The Directive requires that competent authorities have measures in place to prevent the introduction and control the spread of certain listed diseases. These diseases have been divided into two categories; exotic and non-exotic. For bivalve molluscs the exotic diseases are listed as: infection with *Bonamia exitiosa*, infection with *Perkinsus marinus* and infection with *Microcytos mackini*. The non-exotic diseases are listed as: infection with *Bonamia ostreae* and infection with *Marteilia refringens*.

Record Keeping requirements under Article 3 of 95/70/EC states that Member States shall ensure that all farms rearing bivalve molluscs:

1) are registered by the official service; this registration must be kept constantly up to date; and

2) keep a record of:

  2.1) live bivalve molluscs entering the farm, containing all information relating to their delivery, their number or weight, their size and their origin;

  2.2) bivalve molluscs leaving the farm for re-immersion, containing all information relating to their dispatch, their number or weight, their size and destination; and

  2.3) observed abnormal mortality.

This record, which shall be open to scrutiny by the official service at all times, on demand, shall be updated regularly and kept for four years.

Movements of shellfish from outside the EU are required to be accompanied by a suitable animal health certificate, signed by the competent authority

5.6.1.3 Requirements for record keeping under the proposed legislation 2006/88/EC

This new Directive not only requires that aquaculture production businesses keep records of all movements of shellfish to and from their sites, but that these records are to be kept by other shellfish businesses, including depuration plants and potentially by transporters and some processing plants. These records would include all movements of seed shellfish to shellfish farms, movements between farms and also movements from farms to the place of final processing. However, there is a provision in the regulations that would allow shellfish farmers who share the same mollusc farming areas to apply for a shared authorization. This reflects the spatial distribution of farms within hydrographic areas, and the effect of this on the potential spread of disease within these areas.

5.6.1.4 Record keeping under the EU Food Hygiene regulations

This legislation requires that each consignment of live bivalve molluscs is accompanied by a movement document which states the place and date of harvesting together with the details of the harvester. This is to allow full traceability in the event of a human health disease outbreak in the consumers of harvested shellfish. There are controls on the harvesting of shellfish, which cannot be taken from areas where there is no known microbiological classification, unless they are "seed" shellfish not destined for immediate consumption.

5.6.1.5 Movements of shellfish (what species are transported where?)

Movements of shellfish for aquaculture can broadly be divided into four categories:

1) movement of wild caught seed for relay onto managed farms;

2) movement of hatchery cultured seed;
3) movement of farmed stock to other farms for ongrowng to final market size;
4) movements of farmed or wild stock relayed for depuration or at a dispatch centre prior to sale; and
5) movement of live shellfish to the final market (human consumption).

Typical movements that take place within the aquaculture trade may include:

- native and Pacific oyster seed from hatcheries to nursery and ongrowing sites;
- part grown native and Pacific oysters from nursery sites to ongrowing sites;
- clam seed from hatcheries to ongrowing sites;
- scallops and queens from natural spat collection sites to ongrowing sites;
- mussels from natural seed beds to ongrowing sites; and
- shellfish relaid for depuration or held at a dispatch centre prior to sale

These movements may take place either locally within shellfish harvesting areas, between shellfish harvesting areas within a region/country, between countries within economic regions (Europe), or internationally between economic regions (USA – Europe). Examples of international movements include the introduction of oysters to Europe from America during the 19th and 20th centuries, and more recently large-scale translocation of seed mussel from UK to Eire, and Ireland to the Netherlands.

Although the majority of movements of shellfish for aquaculture are arguably all driven by economic reasons (Mortensen *et al.*, 2006), some recent stock transfers have been made because there is a shortfall in local supply. This reflects both the variable nature of recruitment to wild sources of stocks of seed shellfish and the lack of commercially cultivated juvenile shellfish for some species, which are often uneconomic to produce.

Details of movements between ICES countries are hard to collate, largely as there is no formal arrangement for all of these transfers to be recorded, and data has to be extrapolated from what information is available. The information offered in the table below is therefore a best guess using the resources available, and whilst it does give an idea of the extent of these movements, should not be considered definitive.

Table 5.1. Shellfish movements within ICES countries.

ICES Member Country	MOVEMENTS OF SHELLFISH			
	Local	National	Regional[1]	International
Belgium	X	X	X	
Canada	X	X		
Denmark	X	X	X	
Estonia				
Finland				
France	X	X	X	X
Germany	X	X	X	X
Iceland				
Ireland	X	X	X	
Latvia				
Lithuania				
Netherlands	X	X	x	
Norway	X	X	X	
Poland				
Portugal	X	X		
Russia				
Spain	X	X		
Sweden	X	X	X	
UK	X	X	X	X
USA	X	X		X

[1] **Economic area e.g. Europe.**

5.7 Potential effects and implications

5.7.1 Introduction

In this section the effects of shellfish relocations on the *geographic distribution of marine organisms*, *indigenous shellfish stock traits* and the *potential implications* for regional shellfish culture operations are reviewed and reported on. Topics that will be covered in the next years are:

1) What is the definition of a transfer? Where is the border of an area? Direct (transferred organism is non-indigenous), indirect (transferred organism carries non-indigenous species as a hitchhiker species [fouling organisms / epifauna and epiphytes, organisms within the soft tissue, cysts in sediment]), transfer of bait.

2) What is non-indigenous? (established and not established).

3) What non-indigenous species are causing effects

4) What are the effects on recruitment, loss of cultivated organisms, sterilization, reduced fitness and fecundity, less meat content, competition, risk of predation, or change in genetic composition, diversity and polymorphism, and physiological and morphological traits?

5) Scientific tools to support policy decisions on cultured shellfish transfer issues (e.g. risk assessment of shellfish transfers).

6) Recommendations to farmers and policy makers

7) Conclusions

A start was made on the potential genetic implications of transfers for wild and cultured stocks of shellfish. And some relevant new information about transfers was summarised.

5.7.2 Potential genetic implications for wild and cultured stocks

Results of the EU project GENIMPACT are summarised below.

GENIMPACT; WP1 Genetics of domestication, breeding and enhancement of performance of fish and shellfish; Pacific cupped oyster – *Crassostrea gigas*

The pacific oyster was introduced in Europe after the viral disease that crashed the Portuguese oyster (*Crassostrea angulata*) population. Currently there's contact between the species in two areas of the world, between France and the south of Portugal and between Japan and Taiwan. In these regions hybrids are found. This hybridisation has its impact on the *C. angulata* population in Southern Europe.

Pacific oyster spat is mainly obtained from captures but about 20% of pacific oyster spat is derived from hatcheries. Hatcheries mainly produce triploid spat, which is not considered as a safe genetic confinement tool as triploids occasionally breed. The effects of the partial sterility of triploids are poorly known. Another tread to wild populations is the use of tetraploid broodstock when they escape from quarantine, as their fitness relative to diploids and the impact of their breeding with diploids is still unknown.

Beaumont A., Gjedrem T., Moran P., Blue mussel – *Mytilus edulis*, Mediterranean mussel *M. galloprovincialis* (Genimpact final scientific report)

The mussel species *Mytilus edulis* and *M. galloprovincialis* have a huge overlap in space from France to Scotland. *M. edulis* is found to be homogeneous throughout its range while *M. galloprovincialis* is genetically subdivided into a Mediterranean and an Atlantic group. *Mytilus trossulus* also exists in discrete areas. On places where these species occur hybrids are found, but little is known about the precise distributions of both mussel species and their hybrids. Without this basic information it is impossible to estimate the genetic influence of mussel aquaculture on wild populations.

The three main cultivation methods for mussels (bottom culture, suspended culture and bouchot culture) have their own specific characteristics. Therefore there may be a genetic impact due to genotype-specific mortality in areas where aquaculture is the major source of mussel biomass.

Hatchery production of mussels is very low in Europe, for this reason the risk of genetic impact from hatchery mussels is currently neglible.

Lapègue S, Beaumont A., Boudry P., Foulletquer P, European flat oyster – *Ostrea edulis* (Genimpact final scientific report)

Ostrea edulis occurs naturally from Norway to Morocco in the North-Eastern Atlantic and in the whole Mediterranean basin. The species has also been introduced in the United States, from Maine to Rhode Island (1930s and 1940s) and in Canada (about 30 years ago). Mediterranean flat oysters have more genetical variability than the Atlantic population. The North American populations were derived from the Atlantic population.

Most flat oysters are grown from wild captured seed but in France, the UK and Ireland hatcheries are producing flat oyster spat. Hatchery cultured spat has usually a reduced genetic variability and could reduce the variability of the natural population. Polyploid flat oysters could be produced but are currently not farmed.

No large selective breeding programmes have been started for *O. edulis*, but some experiments to improve resistance to *B. ostreae* have been carried out. Results show a higher survival rate and a lower prevalence of the parasite in selected stocks but also a reduced genetic variability in mass selected populations.

Beamont A., Gjedrem T. Scallops – *Pecten maximus* and *P. jacobaeus* (Genimpact final scientific report)

Scallop spat is obtained from wild-captures and from hatcheries. Hatchery scallops can easily escape from farms, but since scallop aquaculture is very small scaled in Europe (213 tonnes in 2004 whereas the landings of captured fisheries exceeded 50000 tonnes), the effect on wild populations is not significant.

5.7.3 New information that was published after the WGEIM 2006 report

Wijsman and Smaal (2006): In Irish and UK marine waters, 74 exotic species are present, of which 22 are not found in the Oosterschelde. None of these 22 exotic non-indigenous species were either found on the mussel plots in Ireland and Wales, nor in the transport samples. This, however, does not completely exclude the possibility of their transport. From literature data and expert judgment we assessed that 14 out of these 22 species there is a chance to survive transport, and establish populations in the Oosterschelde. With respect to the effect, out of the 22 exotic non-indigenous species the possible negative impact is considered high for three species. These are the algae *Alexandrium tamarense* and *Gyrodinium* cf. *aureolum* and the gastropod *Urosalpinx cinerea* (American oyster drill). The algae can lead to toxic blooms and the American oyster drill predates oyster spat and can have a devastating effect on oyster beds. The algae species already occur in and along the North Sea, and could be able to find their own way to the Oosterschelde. The American oyster drill has been found locally on the Essex and Kent coasts at the East coast of the UK, and precautions are taken to prevent dispersal to the mussel production areas.

Wijsman et al. (2007a): In total 51 exotic non-indigenous species are known for the Norwegian coastal waters. Fourteen of these species are new for the Dutch coastal waters and can be regarded as target species, which could potentially be introduced into the Wadden Sea with the import of mussels from Norway. Species with highest chance of successful introduction are the algal species *Aglaothamnion halliae*, *C. fragile* ssp *scandinavicum*, *Verrucophora farcimen*, *Karlodinium micrum* and *Olisthodiscus luteus*, the polychaete *Scolelepsis korsuni* (due to the lack of information on this species and the precautionary principle that is used in this study) and the goose barnacle (*Lepas anatifera*). Species with the highest potential impact once introduced are the algal species *Verrucophora farcimen* and *Olisthodiscus luteus*, the American lobster (*Homarus americanus*), the king crab (*Paralithodes camtschaticus*) and the Manila clam (*Ruditapes philippinarum*). Due to the lack of information also the polychate *Scolelepis korsuni* is scored as a species with potential high impact (precautionary principle).

Wijsman et al. (2007b): In total 41 exotic non-indigenous species are known for the Swedish coastal waters. Ten of these species are new for the Dutch coastal waters and can be regarded as target species, which could potentially be introduced into the Wadden Sea with the import of mussels from Sweden. Species with highest chance of successful introduction are the algal species *Verrucophora farcimen* and *Aglaothamnion* *halliae* and the crustacean *Pilumnus spinifer*. Species with the highest potential impact once introduced are the algal species *Verrucophora farcimen*, *Oxytoxum criophilum*, *Pleurosira laevis Codium fragile* and the trematode *Pseudobacciger harengulae*. The study shows that the algae *Dissodinium pseudocalani*, *Oxytoxum criophilum*, *Pleurosira laevis*, *Verrucophora farcimen* and *Codium fragile* and the trematode *Pseudobacciger harengulae* present most risks.

The risk assessments of these studies concluded that transport of mussels from Ireland, the UK, Sweden and Norway to the Dutch production areas can be allowed.

5.8 Recommendations

1) The WGMASC recommends that ToR c) remain active to complete a review on the significance of bivalve aquaculture transfers between sites (local, national, international) to wild and cultured bivalve stocks. The focus of the ToR will be on guidelines and records in ICES countries related to the transfer of cultured species, and on effects of shellfish relocations on the geographic distribution of marine organisms, indigenous shellfish stock traits (genetic, physiological, morphological, recruitment, competition, and predation) and the potential implications for regional shellfish culture operations are reported.

2) The WGMASC recommends that key persons of WGEIM and WGITMO dealing with the introduction of aquatic exotic species via shellfish transfers should be invited to the next WGMASC meeting to participate in preparing a joint report, identify information gaps and recommend specific research goals and management advice.

5.9 References

Ambariyanto, and Seed, R., 1991. The infestation of *Mytilus edulis* Linneaus by Polydora ciliata (Johnston) in the Conwy estuary, North Wales. J. Moll. Stud., 57, 413–424.

Calvo-Ugarteburu, G., McQuaid, C. D., 1998. Parasitism and invasive species: effects of digenetic trematodes on mussels. Mar. Ecol. Prog. Ser., 169, 149–163.

Camacho, A., Villalba, A., Beiras, R., Labarta, U., 1997. Absorption efficiency and condition of cultured mussels (*Mytilus edulis galloprovincialis* Linneaus) of Galicia (NW Spain) infected by parasites Marteilia refringens Grizel *et al.* and Mytilicola intestinalis Steuer. J. Shellfish Res., 16, 77–82.

Denis, Jean-Francois. 2001. Sea Technology.

Desclaux, C., de Montaudouin, X., Bachelet, G., 2004. Cockle Cerastoderma edule population mortality: role of the digenean parasite Himasthla quissetensis. Mar. Ecol. Prog. Ser., 279: 141– 150.

Dethlefsen, V., 1975. The influence of Mytilicola intestinalis Steuer on the meat content of the mussel *Mytilus edulis* L. Aquaculture, 6: 83–97.

European Directive 91/67/EEC COUNCIL DIRECTIVE of 28 January 1991 concerning the animal health conditions governing the placing on the market of aquaculture animals and products (OJ No. L 46, 19.02.91, p. 1)

European Directive 2000/60/EC Official Journal of the European Union (OJ No L327/1 22.12.2000)

European Directive 2006/88/EC Official Journal of the European Union 24.11.2006 (OJ No L328/14 24.11.2006)

FAO. 1997. FAO Database on Introduced Aquatic Species. FAO Database on Introduced Aquatic Species, FAO, Rome.

IECS Code of Practice on the Introduction and Transfers of Marine Organisms 2005 ICES. 2005. ICES Code of Practice on the Introductions and Transfers of Marine Organisms 2005. 30 pp.

Lapègue, S., Boudry, P., and Goulletquer, P. 2006. Pacific cupped oyster – *Crassostrea gigas*. *In*: "Genetic effects of domestication, culture and breeding of fish and shellfish, and their impacts on wild populations." D. Crosetti, S. Lapègue, I. Olesen, T. Svaasand (eds). GENIMPACT project: Evaluation of genetic impact of aquaculture activities on native populations. A European network. WP1 workshop "Genetics of domestication, breeding and enhancement of performance of fish and shellfish", Viterbo, Italy, 12–17 June, 2006, 6 pp.

Mortensen, S., Korsnes, K., and Bergh, Ø. 2006. "Eyes Wide Shut" A critical view of aquaculture health management and risk factors in the "real world". Bull. Eur. Ass. Fish Pathol., 26(1) 2006, 2.

Regulation (EC) No 853/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific hygiene rules for food of animal origin (OJ No. L 226/22, 25.6.2004).

Regulation (EC) NO 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of foodstuffs (OJ No L 226/3, 25.6.2004)

Svåsand, T., Crosetti, D., García-Vázquez, E., Verspoor, E. (eds). 2007. Genetic impact of aquaculture activities on native populations. Genimpact fi nal scientifi c report (EU contract n. RICA–CT–2005–022802). 176 p.

Snijdelaar, M., Wiersinga, W., Greutink, T., Van Dam, C., and Paasman, J. 2004. Deskundigenoordeel verplaatsingsproblematiek schelpdieren. Expertisecentrum LNV, Ede

Taskinen, J. 1998. Influence of trematode parasitism on the growth of a bivalve host in the field. Int. J. Parasitol., 28: 599–602.

Tiews, K., 1988. Die Miesmuschel in der O¨ kologie des Wattenmeeres. Inf. Fischwirtsch., 35: 110–112.

Wegeberg, A., Jensen, K., 1999. Reduced survivorship of Himasthla (Trematoda, Digenea)-infected cockles (*Cerastoderma edule*) exposed to oxygen depletion. J. Sea Res., 42: 325–331.

Wegeberg, A. M., Jensen, K., 2003. In situ growth of juvenile cockles, Cerastoderma edule, experimentally infected with larval trematodes (*Himasthla interrupta*). J. Sea Res., 50: 37–43.

Wolff, and Reise, 2002 Oyster imports as a vector for the introduction of alien species into Northern and Western European coastal waters. *In* Invasive aquatic species of Europe: distribution, impacts and management. Edited by E. Leppäkoski, S. Gollasch and S. Olenin. Kluwer Academic Publishers, Dordrecht. pp. 193–205.

Wijsman, J.W.M., and Smaal, A.C. 2006. Risk analysis of mussels transfer. C044/06, Wageningen Imares, Yerseke.

Wijsman, J.W.M., Tamis, J.E., Kaag, N.H.B.M., Karman, C.C., Foekema, E.M., and Smaal, A.C. 2007a. Risk analysis on the import of mussels from Norway into the Wadden Sea. C102/07, IMARES, Yerseke.

Wijsman, J.W.M., Tamis, J.E., Kaag, N.H.B.M., Karman, C.C., Foekema, E.M., and Smaal, A.C. 2007b. Risk analysis on the import of mussels from Sweden into the Wadden Sea. C103/07, IMARES, Yersek.

6 Review the state of knowledge on the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries world wide. (ToR d)

6.1 Background

Climate change has been defined by the United Nations Convention on Climate Change as the "change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and-or the variability of its properties, and that persists for an extended period, typically decades or longer" which includes changes resulting from both natural variability and human activity. Regardless of the source of climate change, interactions with shellfish aquaculture are unavoidable.

The IPCC analysed global climate observations and concluded that "warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level". Recent mean temperatures in the Northern Hemisphere are likely the highest in at least the past 1300 years. Precipitation and the frequency of large precipitation events have increased significantly in many ICES countries. These changes are linked with high confidence to increased runoff and the occurrence of earlier spring discharges and shifts in the geographic distribution and abundance of algae, plankton and fish.

The issue of climate change and the possible impact of temperature rise and hydrodynamic changes on shellfish aquaculture have received little direct research effort. However, climate changes will ultimately impact which species are suitable for farming in a given region and will indirectly influence other factors that influence aquaculture, such as primary production, microalgal biodiversity, the presence of nuisance species, oxygen levels and the incidence of harmful algal blooms (University of Victoria, 2000, Canadian Institute for Climate Studies 2000). The increased carbon dioxide would cause an acidification of the oceans, which may reduce the shell growth of molluscs (Gazeau *et al.*, 2007). Climate change may also cause sea level rise and alter salinity, weather extremes, storm surges, tidal regimes, waves and coastal erosion, all of which can impact shellfish aquaculture with a largely unknown net positive or negative result. It is believed that climate change will impact shellfish aquaculture, particularly in the intertidal zone, but knowledge is needed to more fully identify the threats and potential opportunities. Our task is to consider the current scientific evidence for and effect of climate change in ICES countries and world wide. For example, can summer mortalities in *C. gigas* be attributed to climate change in certain European countries or simply be a result of poor broodstock selection?

To address this ToR, any available evidence on climate change impacts on cultured species needs to be accumulated and assessed. This includes collecting information related to a recent OSPAR request for ICES "to prepare an assessment of what is known of the changes in the distribution and abundance of marine species in the OSPAR maritime area in relation to changes in hydrodynamics and sea temperature." Work by the WGMASC, during this preliminary discussion on this ToR, included reviewing reports on present climate change patterns and specific marine parameters in the North Atlantic that are affected and which may affect shellfish aquaculture. A starting point was to examine predictions of potential changes in the marine environment as revealed by different model scenarios. This report will be expanded in the coming years.

6.2 Climate change: Model scenarios

Modelling of different scenarios (SRES) indicates that for the period 2090 to 2099 the global air temperature will be 1.8 to 4.0°C higher than compared to 1980–1999. The greatest warming will occur in the north and least at the southern ocean. Projected changes in the marine environment during this period include;

- sea ice cover in Arctic will be reduced or disappear, whereas no reduction is expected in the Antarctic
- a sea level rise of 0.18 to 0.59 m is expected
- more extreme weather conditions including heavy precipitation and wind events are expected
- the run-off of freshwater to marine areas will vary significantly from area to area (e.g. the Mediterranean will have a 40% reduction in run-off and the North Sea will have a 10–40% increase in run-off
- change in the geographical range of organisms, diversity, and ecological structure and function
- coastal area are expected to be flooded and any industries in these areas (i.e. shellfish production) are most vulnerable to climate change
- the temperature increase and increased runoff may affect the formation of pycnoclines in coastal areas. This can have implication for the transport of the nutrient rich water to the photic zone that supports microalgae production. A strong pycnocline may increase the frequency of oxygen depletion in specific areas
- a higher frequency of wind events (storms) will affect structures currently used for shellfish aquaculture
- heavy precipitation may increase the run-off of nutrients, supporting a higher primary production. Floods due to heavy precipitation may reduce food safety and sanitary quality, due to run-off of sewage

During the last century the global average sea surface temperature has increased 0.6± 0.2°C. This has important implications for the marine ecosystem. On the scale of marine ecosystems, the effects of climate forcing include:

- changes in biogeographical, physiological and species abundance and range
- changes in seasonal cycles (e.g. food production, migration, reproduction)
- change in food web organisation and trophic interactions
- changes in the distribution and intensity of Harmful Algal Blooms

6.3 Available evidence on climate change effects on aquaculture

In general, any evidence presented on climate change impacts on shellfish aquaculture is not based on cause – effect linkage, but on simple correlation. Considering that these correlations can reflect autocorrelations, anti-aliasing, and/or random processes, the interpretation of climate change related correlations requires awareness and must be supported by reasonable biological understanding of the systems.

It is expected that the largest changes in marine ecosystems will occur at the lower trophic levels, and evidence exists to suggest that phytoplankton seasonal cycles have shifted (Edwards and Richardson, 2004). Such a shift can have a large impact on community functioning if biologically associated linkages are disrupted and populations' cycles are shifted out of phase with seasonal temperature cycles, food production and predator abundance. For example, large scale climate changes have been shown to substantially alter estuarine zooplankton population dynamics owing to interspecies differences in life histories (Costello *et al.*, 2006). Population dynamics of cold-water bivalve species are strongly related to temperature and mild winters in northwestern European estuaries result in low bivalve (*Cerastoderma edule, Macoma balthica, Mya arenaria and Mytilus edulis*) recruit densities and small adult stocks (reviewed by Philippart *el al*., 2003). These authors suggest that the current rapid rate of temperature increase could lead to long periods of poor recruitment of wild bivalve stocks and an increase in warm-water species. Mortality of juvenile bivalves appears to be related to food availability and reproductive strategies are closely linked to exploiting the spring phytoplankton bloom and avoiding peak predator abundance. Temperature changes can cause a mismatch between spawning, phytoplankton production and predator abundance; resulting in high shellfish mortality, low recruitment and cascading effects through higher trophic levels (Philippart *el al*., 2003).

To study possible causes of recent bivalve recruitment failure, Beukema and Dekker (2005) compare long-term data sets (1973 to 2002) of the annual abundance of spat of three of the most important species of bivalves (cockle *Cerastoderma edule*, gaper clam *Mya arenaria*, and Baltic tellin *Macoma balthica*) on Balgzand, a tidal-flat area in the westernmost part of the Wadden Sea. They concluded that the recruitment trends are governed primarily by natural processes, in particular increases in predation pressure on early benthic stages, which in turn appears to be largely governed by the warming climate. The recent disappearance of *M. balthica* from the Spanish part of the Bay of Biscay has been attributed to increased maintenance metabolic rates caused by short-term, but frequent exposure to elevated temperatures resulting increasing summer maxima temperatures (Jansen *et al.,* 2006).

Freitas *et al.* (2007) compared the temperature sensitivity of epibenthic predators with that of their bivalve prey and showed that crustaceans have higher temperature sensitivity and tolerance range compared with both their potential predators and with their bivalve prey. They suggested that a temperature increase can potentially lead to an overall higher predation pressure in these systems with negative impacts on bivalve recruitment. However, prevailing food conditions for bivalves and predators will determine to what extent the potential impacts of an increase in temperature will be realized.

Diederich *et al*. (2004) studied how the Pacific oyster (*Crassostrea gigas*) became established on natural mussel beds in the vicinity of an oyster farm near the island of Sylt (northern Wadden Sea, eastern North Sea) where it was introduced. It took 17 years before a large population were established and analyses of mean monthly water temperatures indicate that strong recruitment coincided with above-average temperatures in July and August when spawning and planktonic dispersal occurs. It was concluded that the further invasion of *C. gigas* in the northern Wadden Sea will depend on high late-summer water temperatures.

Berge *et al.* (2005, 2006) examined interannual variations in ocean temperatures and the increased northward volume transport of Atlantic water and suggested that a recently discovered population of *Mytilus edulis* L. in the high Arctic Archipelago of Svalbard represented a northward extension of the distribution range of blue mussels. This is the first observation of the presence of blue mussels since the Viking Age. These authors presented data indicating that most of the mussels settled as spat in 2002, and that larvae were transported by the West Spitsbergen Current northwards from the Norwegian coast to Svalbard the same year. This extension of the blue mussels' distribution range was apparently made possible by the increased northward mass transport of warm Atlantic water resulting in elevated sea-surface temperatures in the North Atlantic.

The Pacific oyster *Crassostrea gigas*, which was first introduced to Europe by Dutch farmers in 1964, has developed explosively and is expanding its geographical range northwards. *C. gigas* were first discovered in the Norwegian Skagerrak in 2005 and recent surveys have revealed that they have become established in many areas along the Scandinavian coasts. Larval dispersal from other areas, combined with warmer summers, appears to be facilitating survival. *C. gigas* tends to settle in the same areas as *M. edulis* and these native species will likely diminish through overgrowth by oysters, food competition and consumption of mussel larvae (Nehring, 2003).

The native European flatoyster (*Ostrea edulis*) has its northern distribution in Scandinavia where it historically has been cultured mainly in habitats that have higher summer temperature than the coastal and oceanic environment (Strand and Vølstad, 1997). Increasing seawater temperatures and frequency of extreme warm summers during the last decade have supported the development of populations of the oyster in coastal waters of this region.

Bivalves are a net source of CO_2 to the atmosphere via respiration and the deposition of calcium carbonate in shell material, which induces a shift in the seawater carbonate equilibrium to generate, dissolved CO_2. Using data on respiration and calcium carbonate production by the Asian clam, *Potamocorbula amurensis,* which is invasive to San Francisco Bay, Chauvaud *et al.* (2003) assessed their importance as CO_2 sources and provided compelling evidence that bivalve molluscs can markedly influence inorganic carbon cycling by generating CO_2 to the surrounding water. This biogenic CO_2 source is increasing because of the continuing global translocation of molluscs, their successful colonization of new habitats and rapidly growing aquaculture production (Chauvaud *et al.*, 2003).

6.4 Bivalve tolerance to temperature change

The upper temperature tolerance of different bivalve molluscs can serve as a first-order approximation of their susceptibility to global warming trends. The WGMASC will review the upper temperature tolerance of a wide range of bivalve species in the coming years. However, confounding factors also need to be considered as they can make it difficult to predict species responses to regional temperature variations. For example, a bivalve species residing in a more tropical climate is known to be less able to adapt to temperature variation than the same species residing in a temperate waters, owing to the wider thermal tolerance of the later (Compton *et al.*, 2007).

6.5 Responsiveness of Existing Conservation and Protection Policies to Climate Change Issues

A EU report recently reviewed how European policy adapts to marine climate change. *The Water Frame Directive* (WFD) does not directly respond to the effects of climate change. The aim of the WFD is to obtain a "good status" of water bodies. However, this iterative management system with 6 year cycles of monitoring, assessments, and planning is robust to responding to climate change effects. The *NATURE 2000* legislation, designed to protect the most seriously threatened habitats and species across Europe, also does not directly address climate change. However, directives listing the habitat types and organisms protected can adapt in response to scientific advice. An important concept of both *The Common Fisheries Policy* and the Canadian *Oceans Act* is the precautionary approach. This approach may be used to adapt policy to the consequences of climate change.

6.6 Recommendations

1) The implications of climate change to shellfish aquaculture exist within a much broader context of anticipated physical and biogeochemical alterations in coastal marine ecosystems. The WGMASC recommends the close linkage of knowledge and advice generated under our ToR d) with a Science Program on climate change implications for living marine resources.

2) The WGMASC should continue to review the state of knowledge on the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries world wide. Topics yet to be fully addressed include, but are not limited to:

- effects on shellfish resulting from climate change related changes in primary production, run-off, salinity, nutrient dynamics, ocean acidity, etc.
- potential for risk analysis approaches for assessment
- potential opportunities for positive effects such as exploiting new species for aquaculture in northern countries.
- contingency planning to minimize impact

6.7 References

Berge, J., Johnsen, G., Nilsen, F., Gulliksen, B., and Slagstad, D. 2005. Ocean temperature oscillations enable reappearance of blue mussels *Mytilus edulis* in Svalbard after a 1000 year absence. Mar. Ecol. Prog. Ser., 303: 167–175.

Berge, J., Johnsen, G., Nilsen, F., Gulliksen, B., Slagstad, and Pampanin, D. 2006. The *Mytilus edulis* population in Svalbard: how and why. Mar. Ecol. Prog. Ser., 309: 305–306.

Beukema, J.J., and Dekker, R.2005. Decline of recruitment success in cockles and other bivalves in the Wadden Sea: possible role of *climate* change, predation on postlarvae and fisheries. Mar. Ecol. Prog. Ser., 287: 149–167.

Chauvaud, L., Thompson, J.K., Cloern, J.E., and Thouzeau, G. 2003. Clams as CO_2 generators: The *Potamocorbula amurensis* example in San Francisco Bay. Limnol. Oceanogr., 48: 2086–2092.

Compton, T.J., Rijkenberg, M.J.A., Drent, J., and Piersma, T. 2007. Thermal tolerance ranges and climate variability: A comparison between bivalves from different climates. J. Exp. Mar Biol. Ecol., 352: 200–211.

Costello, J.H., Sullivan, B.K., and Gifford, D.J. 2006 A Physical-Biological Interaction Underlying Variable Phenological Responses to Climate Change by Coastal Zooplankton. J. Plankton Res., 28: 1099–1105.

Diederich, S., Thieltges, D.W., and Strasser, M. 2004. Wadden Sea mussel beds invaded by oysters and slipper limpets: Competition or climate control? Helgol. Mar. Res., 60: 135–143.

Edwards, M., and Richardson, A.J. 2004. Impact of climate change on marine pelagic phenology and trophic mismatch. Nature, 430: 881–884.

Freitas, V. Campos, J., Fonds, M., and Van der Veer, H.W. 2007. Potential impact of temperature change on epibenthic predator–bivalve prey interactions in temperate estuaries. J. Thermal Bio., 32: 328–340.

Canadian Institute for Climate Studies. 2000. Sustainable seafood in a changing climate; workshop report, University of Victoria, May 25–26, 2000, available. http://www.cics.uvic.ca/workshop/FinalReport.htm

Gazeau, F., Quiblier, C., Jansen, J.M., Gattuso, J-P., Middleburg, J.J., and Heip, C. 2007. Impact of elevated CO_2 on shellfish calcification. Geophys. Res. Lett., 34.

Jansen, J.M., Pronker, A.E. Bonga, S.W., and Hummel, H. 2006. *Macoma balthica* in Spain, a few decades back in climate history. J. Exp. Mar. Biol. Ecol., 344: 161–169.

Nehring, S. 2003. Alien species in the North Sea: invasion success and climate warming. Ocean Challenge, 13(3): 12–16.

Philippart, C.J.M., van Aken, H.M., Beukemam, J.J. Bos, O.G., Cadee, G.C., and Dekker, R. 2003. Climate-related changes in recruitment of the bivalve *Macoma balthica*. Limnol. Oceanogr., 48, no. 6, pp. 2171–2185.

Strand, Ø., and Vølstad, J.H. 1997. The Molluscan Fisheries and Culture of Norway, p. 7–24. *In*: The history, present condition, and future of the molluscan fisheries of North and Central America and Europe, Volume 3, Europe. Edited by Clyde L. MacKenzie, Jr., Victor G. Burrell, Jr., Aaron Rosenfield, and Willis L. Hobart. NTIS number: PB97–164859. U.S. Dep. Commer., NOAA Tech. Rep. NMFS 129.

Annex 1: List of participants

Name	Address	Phone/Fax	Email
Peter J. Cranford *Chair*	Dept. of Fisheries & Oceans Bedford Institute of Oceanography P.O. Box 1006, Dartmouth, NS B2Y 4A2, Canada	902-426-3277 902-426-6695	cranfordp@mar.dfo-mpo.gc.ca
David Fraser	Fisheries Research Services, Marine Laboratory P.O. Box 101 375 Victoria Road Aberdeen AB11 9DB United Kingdom	+44 1 224 295698	fraserdi@marlab.ac.uk
Adoración Sanchez-Mata	Marine Resources Research Department Marine Research Center (CIMA) Xunta de Galicia Aptdo.13 Vilanova de Arousa, 36620 Spain	34 986500155 Fax 34 986506788	asanchez@cimacoron.org
Bela H. Buck	Alfred Wegener Institute for Polar and Marine Research (AWI) Am Handelshafen 12 D-27570 Bremerhaven Germany Institute for Marine Resources (IMARE) Klussmannstrasse 1 D-27570 Bremerhaven Germany	Tel. ++49(0)471-4831-1868 Fax ++49(0)471-4831-1149	Bela.H.Buck@awi.de
Gesche Krause	Center for Tropical Marine Ecology Fahrenheitstr. 6 28359 Bremen Germany	+ 49-(0)421-23-800-28 Fax: + 49-(0)421-23-800-30	gesche.krause@zmt-bremen.de
Joseph Mazurié	Ifremer, LER/MPL, BP 86, 56470 La Trinité/mer, France	(33)2 97 30 19 19 Fax: (33) 2 97 30 19 00	jmazurie@ifremer.fr
Kris Van Nieuwenhove	Institute for Agricultural and Fisheries Research – Fisheries Fisheries Biology & Aquaculture section Ankerstraat 1 8400 Oostende Belgium	+32.59.569.871 (direct) Fax: +32.59.330.629	kris.vannieuwenhove@ilvo.vlaanderen.be
Michael Gubbins	Cefas Barrack Road Weymouth Dorset DT4 8UB	+44 (0) 1305 206682	Michael.gubbins@cefas.co.uk

NAME	ADDRESS	PHONE/FAX	EMAIL
Øivind Strand	Institute of Marine Research Nordnesgt. 50 Boks 1870 Nordnes N - 5817 Bergen	+ 47 55236367 Fax - + 47 55235384	oivind.strand@imr.no
Pauline Kamermans	Wageningen Institute for Marine Resources and Ecosystem Studies (IMARES) PO Box 77 4400 AB Yerseke Netherlands	+31 (0)113-672302 +31 (0)113-573477	pauline.kamermans@wur.nl
Per Dolmer	Technical University of Denmark, National Institute of Aquatic Resources Kavalergårdden 6, 2920 Charlottenlund Denmark	+4533963433 +4540437655	pdo@difres.dk

Annex 2: Agenda

Tuesday 1 April 2008

09:00 Taxis arranged for transport from Inn on the Park. Meeting in FRS conference room

09:30 Welcome to FRS by Directorate

09:45 Introductions and update on ICES activities – Peter Cranford

- General discussion of ICES activities and Terms of Reference
- Adoption of agenda

10:30 *Health Break*

11:00 Plenary to develop work plan, identify subgroups, subgroup leaders and rapporteurs

12:30 **Lunch**

13:30 Subgroup sessions (ToR = WGMASC Term of Reference):

- ToR b): *Evaluation framework for shellfish aquaculture impacts*
- ToR c): *Significance to wild stocks of bivalve aquaculture transfers between sites/countries*
- ToR d): *Climate change and shellfish aquaculture distribution and production*

15:00 *Health Break*

15:15 – 18:00 Continue ToR subgroup sessions

Wednesday 2 April 2008

08:45 Taxis leave Inn on the Park.

09:00 Plenary – brief overview of work status

09:30 Reconvene ToR subgroup sessions

10:30 *Health Break*

11:00 Reconvene ToR subgroup sessions

12:30 **Lunch**

13:30 Reconvene ToR subgroup sessions

15:00 *Health Break*

15:15 – 18:00 Plenary with overview of ToR b), c) and d) status by subgroup leaders and discussion of ToR a): *Emerging shellfish aquaculture issues and science advisory needs*

Thursday 3 April 2008

09:00 Plenary Session: review and discus 1st draft of WGMASC report

10:30 *Health Break*

11:30 Revision of WGMASC report in subgroups.

13:00 **Lunch**

13:30 Revision of WGMASC report in subgroups.

14:00 Plenary Session:

- Election of new Chair
- Location of next meeting
- Discussion and drafting of recommendations

15:30 *Health Break*

16:00 Plenary Session (cont.):

- Prepare Executive Summary
- Review and adoption of the scientific text of the report
- Discussion on any new Terms of Reference

1800 Meeting Adjournment

Annex 3: WGMASC terms of reference for the next meeting

The **Working Group on Shellfish Aquaculture** [WGMASC] (Chair: Pauline Kamermans*, the Netherlands) will meet in Bremerhaven, Germany from 7–9 April 2009 to:

a) identify emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment. The task is to briefly highlight new and important issues that may require additional attention by the WGMASC and/or another Expert Group as opposed to providing a comprehensive analysis;

b) complete the development of a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone by identifying a suite of tools (e.g. modelling, technologies) and indicators (ecosystem and shellfish performance) specific for monitoring ecosystem status in relation to shellfish aquaculture and for evaluating ecosystem quality objectives and effects on the productive capacity of coastal systems. This will also provide guidelines for monitoring programmes and the selection of management reference points (operational objectives) and mitigations;

c) review knowledge and report on the significance to wild stocks of bivalve aquaculture transfers between sites/countries. This will include information on what species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species. Also, review and assess: the potential for transfer of non-indigenous species and diseases; the potential genetic implications for wild stocks; the impact on recruitment to existing stocks by large scale transfers, and scientific tools for decision support on cultured shellfish transfer issues; and

d) review the state of knowledge on the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries world wide.

WGMASC will report by 30 April 2009 to the attention of the Mariculture Committee.

Supporting Information

Priority:	WGMASC is of fundamental importance to ICES environmental science and advisory process and addresses many specific issues of the ICES Strategic Plan. The current activities of this Group will lead ICES into issues related to the ecosystem affects of the continued rapid development of shellfish aquaculture, especially with regard to the application of Ecosystem Based Management, and the implications of changing environmental conditions on shellfish cultures Consequently, these activities are considered to have a high priority.

Scientific justification and relation to action plan:	Action Plan No: 1. **Term of Reference a)** For the WGMASC to be responsive to the rapidly changing science advice needs of aquaculture and environmental managers, important emerging shellfish aquaculture issues need to be rapidly identified and screened for potential science advisory needs to maintain the sustainable use of living marine resources and the protection of the marine environment. The intention is for this activity to flag issues that may require future attention and communication between one or several ICES Expert Groups. The Chair of the WGMASC will cross-reference all work with the Chairs of the MCC and relevant Working Groups. **Term of Reference b)** Shellfish production accounts for half of the mariculture production in ICES. As such, issues related to shellfish production, in relation to the environment and technological development of the industry need to be addressed within ICES. A framework is needed for the integrated evaluation of the effects of shellfish aquaculture activities in the coastal zone consisting of a suite of tools (e.g. modelling, technologies) and indicators (ecosystem and shellfish performance) specific for monitoring ecosystem status in relation to shellfish aquaculture and for evaluating ecosystem quality objectives and effects on the productive capacity of coastal systems. Science-based decision support is needed for the development of an environmental monitoring framework, based on identification of predetermined impact limits (operational thresholds) intended to trigger shellfish culture management actions. The Chair of WGMASC will cross-reference all work with the Chairs of the MCC and the WGEIM. **Term of Reference c)** Different shellfish life stages are transported from hatcheries and field sites to new culture sites, and often cross international boundaries, with potential implications for the introduction of non-indigenous species and diseases and the potential for interactions with wild stocks (impact on recruitment, genetic composition, diversity and polymorphism, and physiological and morphological traits). There is a need to identify the significance of shellfish relocations on the geographic distribution of wild stock traits. The significance to wild stocks of such transfers requires information on what species are transported where, what records are kept, and what guidelines are in place in ICES countries related to the transfer of cultured species. Scientific tools for decision support on cultured shellfish transfer issues should be reviewed and assessed. The Chair of WGMASC will cross-reference all work with the Chairs of the MCC, WGEIM, WGPDMO and WGITMO. **Term of Reference d)** Climate variability affects the recruitment and production of important commercial species and affects site suitability for shellfish culture. Increased knowledge on the effects of climate change on shellfish culture is needed to predict and assess impacts on aquaculture distribution and production. The Chair of WGMASC will cross-reference all work with the Chairs of the MCC and the WGEIM.
Resource requirements:	The research programmes which provide the main input to this group are already underway, and resources are already committed. The additional resource required to undertake additional activities in the framework of this group is negligible.
Participants:	The Group is normally attended by some 10 – 12 members and guests.
Secretariat facilities:	None.
Financial:	No financial implications.

Linkages to advisory committees:	ACOM.
Linkages to other committees or groups:	There is a working relationship with all the groups of the Mariculture Committee and specifically the WGPDMO, and WGEIM and the work is relevant to WGICZM.
Linkages to other organizations:	The work of this group is aligned with similar work in GESAMP, WAS, and EAS and numerous scientific and regulatory governmental departments in ICES countries.

Annex 4: Recommendations

Recommendation	For follow up by:
1. The recommended management framework under development for shellfish culture should be compatible with ecosystem management approaches under development throughout ICES countries. Stronger linkages are recommended within the ICES Science Structure to support the evaluation and management of human impacts in the coastal zone. Towards facilitating the integration of advise on management frameworks from the WGMASC (stemming from ToR b) activities) with advise from other EGs (e.g. WGICZM), a Science Program on coastal zone ecosystem-based management is recommended with a ToR that includes provision of guidelines for setting operational thresholds for managing human activities.	ConC, MCC
2. The implications of climate change to shellfish aquaculture exist within a much broader context of anticipated physical and biogeochemical alterations in coastal marine ecosystems. The WGMASC recommends the close linkage of knowledge and advice generated under our ToR d) with a Science Program on climate change implications for living marine resources.	ConC, MCC
3. The WGMASC recommends to continue to identify and report on emerging shellfish aquaculture issues and related science advisory needs for maintaining the sustainability of living marine resources and the protection of the marine environment.	MCC
4. The WGMASC recommends continuing work in 2009 towards completion of a recommended framework for the integrated evaluation of the impacts of shellfish aquaculture activities in the coastal zone. Additional expertise is needed within the WGMASC to review ICZM legislation and policies in North America. This may best be achieved through an appointment of an expert by the Chair for participation in the next WGMASC annual meeting.	MCC
5. The WGMASC recommends that ToR c) remain active to review the significance of bivalve aquaculture transfers between sites (local, national, international) to wild and cultured bivalve stocks. The focus of the ToR will be on guidelines and records in ICES countries related to the transfer of cultured species, and on effects of shellfish relocations on the geographic distribution of marine organisms, indigenous shellfish stock traits (genetic, physiological, morphological, recruitment, competition, and predation) and the potential implications for regional shellfish culture operations are reported.	MCC
6. The WGMASC recommends continuing to review the state of knowledge on the evidence for and effect of climate change on shellfish aquaculture distribution and production in ICES and countries world wide.	MCC
7. WGMASC recommends that key persons of WGEIM and WGITMO dealing with the introduction of aquatic exotic species via shellfish transfers should be invited to the next WGMASC meeting to participate in preparing a joint report, identify information gaps and recommend specific research goals and management advice.	MCC, WGEIM, WGITMO
8. The members of the WGMASC unanimously recommend that Pauline Kamermans (The Netherlands) assume the responsibilities of Chair of the WGMASC in 2009 and that the next annual meeting take place in Bremen, Germany.	MCC